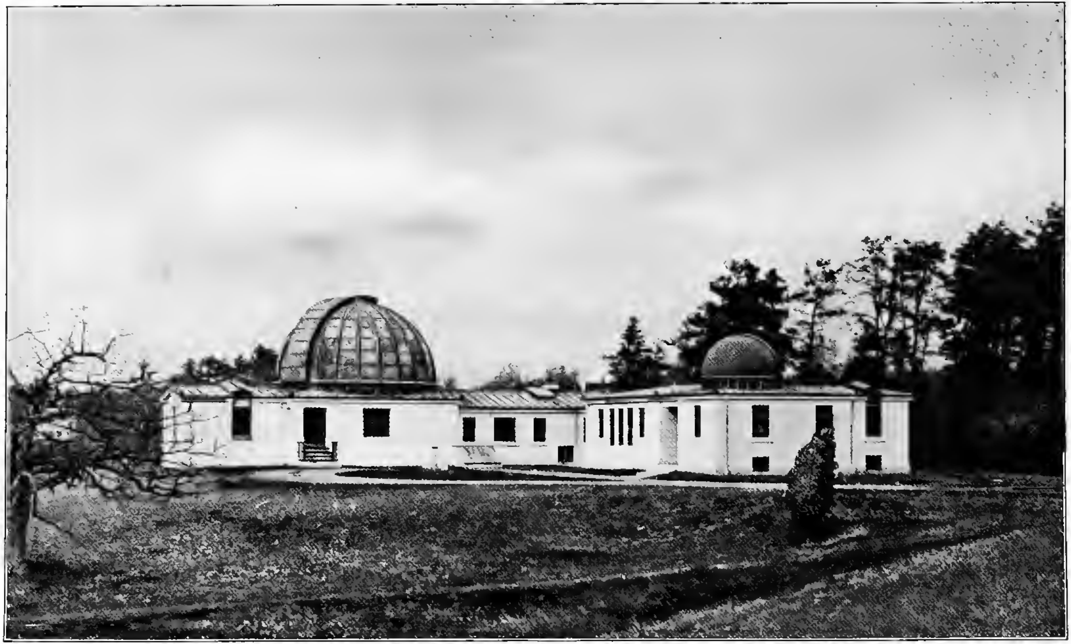
EXERCISES IN ASTRONOMY

WHITING



The Whitin Observatory of Wellesley College

Left to right: Bamberg prismatic transit, twelve-inch Clark telescope, concave grating spectroscope, libraries and computing rooms, laboratory with spectrum laboratory below, six-inch Clark telescope, small transit

DAYTIME AND EVENING EXERCISES IN ASTRONOMY

FOR SCHOOLS AND COLLEGES

BY

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PREFACE

Astronomy is the last of the sciences to use the laboratory method in teaching its elementary classes. The reason of this is not far to seek. Since no instrument has been invented capable of piercing the clouds, observational work has always been dependent on the caprice of the weather. Photography now furnishes perfect representations of sun, moon, planets, and stars, for daytime study; also many forms of illustrative apparatus can be used by the student to awake and cultivate his imagination and furnish, at first-hand, data for scientific reasoning.

This oldest of the sciences, which has heretofore been a rigid discipline for the few, should now take its place beside the others as a training in the scientific method for the many who pursue the subject chiefly for information and culture.

The management of schools and colleges should make the same allowance of time and money for laboratory instruction in this as in the other sciences; there should be a laboratory, a demonstrator, and fixed hours for students' daytime work. Besides the ordinary instruments of an observatory there should be collections of photographs, charts, and apparatus for the students' own handling.

The only astronomical laboratory books known to the writer are those of the South Kensington School of Science in London, and of Miss Byrd and Professor Robert Willson. These admirable handbooks outline comparatively little work which can be done in the daytime, the only time which can be controlled independently of the weather.

The following exercises have been proved to be practical by several years' use with classes of sixty to a hundred, handled in divisions of about fifteen, working two hours a week during the academic year.

In this work the student is, whenever possible, left to draw his own conclusions from data discussed. The American Ephemeris is in constant use, photographs of objects in the sky furnish the "specimens" for inspection, and in this subject, as in botany or zoölogy, "sharpening the pencil sharpens the eyes" — to draw the object fixes the attention upon details of structure. The graph is often used to show the relation between variables, and from it the student can often discover for himself great laws.

Moreover the intelligent person, as well as the professional astronomer, should understand the methods by which, through the daytime study of photographs of the sky taken at night, the great advances in astrophysics have been made. In this subject, as in physics, laboratory exercises can show the methods of research and prepare for it. Most plate work must be left for a second-year course, but a few sample exercises are given. The greatest modern advances in astronomy have been made by the spectroscope, and none of these can be discussed with any degree of comprehension without some laboratory work in spectrum analysis. It would be well if in the high schools simple work with the spectroscope were substituted for some of the less "juicy" experiments now included in the beginning course in physics. As it is, no knowledge of the subject can be counted on, and spectroscopes and their accessories should be provided for work in astronomy.

While this daytime work has high value, it cannot for a moment be advocated to take the place of observation in the open. All is but a means to an end, and the student should never be permitted to bend over chart or plot without fully realizing that it is a strip of the sky overhead that he is considering.

By means of daytime preparation, however, the regular program of evening observations can be greatly helped. With this, a short time out of doors, often under circumstances of more or less uncontrollable discomfort, accomplishes wonders. Directions for the record of observations with the telescope are given, with suggestions for the consultation of the Ephemeris or other publications for accurate descriptions and data.

Every student should, of course, be able to identify the constellations in the sky, and to point out objects which a field glass will reveal. The star names and the mythological figures pictured on the old maps should not be omitted, because of the allusions to them which constantly occur in both modern and classic literature. It is best not to study all the constellations at once, but to prepare for observation as they appear in succession during the academic year.

As one looks at the sky the brighter stars seem to form geometrical figures which catch the eye; within and around these the other stars can be found by alignment. It is worth while to become very familiar with these "catch figures" by sketching them on the star atlas with a pencil in the daytime; they are then quickly recognized in the sky at night. The catch figures used in these exercises are those longest in use; many of them from the old atlas of Burritt.

It can be seen then that the ideal equipment for astronomy is an observatory near enough to the centers of student life to be accessible, equipped with the best instruments. There should be a large laboratory where the students may meet for one of their astronomy exercises in the week, in sections of about fifteen, for the accustomed two consecutive periods of individual work under the direction of a demonstrator. The best books, photographs, charts, and valuable material of the observatory should be brought out for the first-year class. From this class may come the astronomers and the patrons of astronomy of succeeding years.

In general, it is desirable to have the exercises follow as nearly as possible the plan of the lectures and recitations, but orderly arrangement does not seem possible when the objects for consideration are beyond control. Jupiter or Saturn may be visible only in the fall, when students hardly know the difference between a planet and a star; or a comet or "new star" may appear. In these cases students can obtain records of personal observation, and thus have a body of facts to work with when the topic comes up in its proper sequence.

Suggestions for these exercises have come from many sources through a long period. Professor Pickering, director of Harvard Observatory, who opened the first students' laboratory in physics, inspired the writer to attempt students' daytime work in astronomy. General acknowledgment is hereby made for all help, and the hope expressed that these exercises may form a slight contribution to the better teaching of the only science dealing with matter which takes thought off this little planet, and gives those larger conceptions of time and space which stretch the mind and furnish proper perspective for other subjects.

SARAH F. WHITING

WHITIN OBSERVATORY, WELLESLEY COLLEGE

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LIST OF APPARATUS

I. Apparatus for Illustration

Eighteen-inch celestial globe.
Twelve-inch terrestrial globe.
Andrews's tellurion or McVicar's globe.
Gardner's season apparatus.
Columbia planetarium.
Sun-path model.
Willson's miniature equatorial and altazimuth.
Stonyhurst sun disks.
Serviss's star and planet finder.

The apparatus listed above can be obtained through the J. L. Hammett Company, Boston, Massachusetts.

Lemaire field glass, the diameter of the object glasses twenty-four ligne.
Ives's simplex normal spectroscope.
Browning's miniature direct-vision spectroscope. With this small spectroscope all observations may be taken, even to show the coincidence of the *D* line with the sodium line.
Prism spectroscope and accessories for observing the spectra of the lighter metals.
Induction coil and Plücker tubes for showing spark spectra.
Spektraltafel von Kirchhoff und Bunsen, also the colored charts of Huggins and Miller and of Vögel.
Trouvelot's Atlas of Celestial Objects (out of print, but owned by most observatories).
Dürchmusterung des Nordlichen Himmels, with the accompanying text.
Uranometria Argentina (charts of the southern sky).

The field glasses, spectroscopes, and charts are furnished by many apparatus dealers, the charts of the northern sky through dealers in foreign books, the charts of the southern sky through the Cordoba Observatory. Maps of the southern sky in the star atlases can be used if the larger charts are not at hand.

Frame for the illumination of lantern slides.

Screen for projecting sun spots.

These can be made by a carpenter. Sets of lantern slides may often be left for inspection on the support, and changed at intervals. For example, a set showing the complete history of Halley's comet, or famous meteorites, or any other set of pictures which it is desirable to study side by side.

II. Apparatus for Individual Work of Students

Seasonal twilight chart.

Constellation finder.

Six-inch erasable globe.

Hammett's planisphere.

Each student should be supplied with the above apparatus.

Twelve-inch celestial globe.

The solar calculator.

One globe and solar calculator will suffice for each two students.

Colas's map of the moon or the Handy Map of the Moon.

Colas's map of the moon, mounted on cloth, should be tacked to large easels, and one should be provided for each four students.

The American Ephemeris, which can be ordered from the Superintendent of Documents, Washington, D.C.

Viewing-frame for Harvard glass photographs, 8 by 10 inches.

Eyepiece for use with the glass photographs. These can be obtained of the Alvan Clark and Sons Corporation, Cambridgeport, Massachusetts.

Centimeter paper and notebook supplies.

Protractors, compasses, centimeter rulers, paper centimeter scales, etc.

The above apparatus, where not otherwise stated, can be obtained of the J. L. Hammett Company, Boston, Massachusetts. All the apparatus listed is useful and desirable, but selections can be made in beginning a student's laboratory, and additions may be provided from year to year.

LIST OF PHOTOGRAPHS AND GLASS PLATES

Selected regions of the moon: for example, Theophilus–Cyrillus–Katharina; Ptolemy–Alphons–Azachael; Clavius–Tycho; Copernicus; Mare Crisium; Mare Serenitatis; Mare Humorum; Sinus Iridum; the full moon, showing white streaks.

It would be desirable to put into the hands of each student a little booklet of half-tone pictures of different regions of the moon, but this is not yet on the market.

Sun-spot photographs in series, a set for each student.

The Pleiades, with enveloping nebulæ.

Double cluster in Perseus.

Globular cluster in Hercules.

Præsepe in Cancer, as an example of an open cluster.

N. G. C. 2682 in Cancer, as an example of a close cluster.

47 Tucanæ, the region of the Southern Cross, and other photographs of objects in the southern sky.

Messier 5 in Libra.

Two sets of photographs of Messier 5, taken at two different epochs, serve to show the variability of numerous stars in this globular cluster. A pair of these photographs should be provided for each student.

Harvard Map. This is a series of glass chart photographs of the entire sky. The following plates cover the more interesting regions: Numbers 12, 14, 18, 25, 42, 45, 50.

Spectrum plates taken at Harvard Observatory with the objective prism. Interesting plates which contain many types of stars are of the region of the Pleiades, of chi Cygni, of R Cygni, of Wolf-Rayet stars in Cygnus.

Twenty-five selected glass plates of the globular cluster omega Centauri, taken at different epochs. These plates suffice to obtain the light curve of several of the numerous variables in this cluster.

Note. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

DIRECTIONS FOR NOTEBOOKS

1. Reserve three pages for an index, which should be kept up to date, and head successive pages as follows:

Observations with the Telescope.
Naked-eye Observations.
Laboratory Exercises.

2. Head the page of the notebook on which each new exercise is recorded with the date, the proper heading for the exercise, and the student's name.

3. Use unruled paper for drawings, horizontally ruled paper for notes, and checked centimeter paper for graphs. When tables of figures are to be recorded, rule columns vertically in pencil.

4. Make all drawings with sharp pencil; use ink for all else. A fine pen and India ink may be used to advantage in tracing graphs.

5. The notebook should in every case tell briefly and clearly what the student has seen or done; directions should not be copied.

EXERCISES IN ASTRONOMY

EXERCISE I

COÖRDINATES OF STARS FROM GLOBE AND STAR CATALOGUE

Object. It is of the greatest importance to become familiar with the two universal coördinates of the stars, right ascension and declination. To measure these coördinates for twenty of the brightest stars will certainly make their meaning clear; moreover, the student will at once learn the names of these stars. It happens that the plates for most globes show the places of the stars given in catalogues for the middle of the last century. By looking up the coördinates of the stars from a catalogue which brings their places down to 1900, the student finds a systematic increase in all the right ascensions which he must account for.

Directions. Make six columns in your notebook as follows:

Constellation	Star Name	Globe		Catalogue	
		R.A.	Dec.	R.A.	Dec.

Write in the first two columns the following list of stars:

Above 0 Magnitude	
Alpha Canis Majoris	Sir′ius
*Alpha Argus	Canō′pus
0 Magnitude	
*Alpha Ērid′ani	Ar′chenar
Alpha Aurī′gæ	Capel′la
Beta Orionis	Rī′gel
Alpha Canis Minoris	Pro′cyon
Alpha Boö′tis	Arctū′rus
*Alpha Centau′ri	
Alpha Lȳ′ræ	Vē′ga
1st Magnitude	
Alpha Tauri	Aldeb′aran
Alpha Orionis	Bet′elguese (gerz)
Beta Geminorum	Pol′lux
Alpha Leonis	Reg′ulus
*Alpha Crucis	
Alpha Virginis	Spī′ca
*Beta Centauri	
Alpha Scorpii	Antā′res
Alpha Aq′uilæ	Altair′
Alpha Cygni	Den′eb
Alpha Piscis Austrā′lis	Fo′malhaut

Next, with a flexible scale of brass, or better, of paper, measure on the globe the right ascension and declination of each of these stars, and record in the third and fourth columns.

Finally, look up these stars in the "Catalogue of 1520 Bright Stars" from the Harvard Annals, or in the American Ephemeris, or in some catalogue which gives places for 1900.

* The five stars marked with an asterisk are invisible in intermediate northern latitudes.

Remembering that the places on the globe are for the epoch 1850, and that those of the catalogue are for 1900, record in your notebook answers to the following questions:

1. How do the right ascensions as you measure them compare with those from the catalogue?

2. In what two ways might you account for the difference?

3. Which of the two ways is more rational?

NOTE. Hipparchus discovered the precession of the equinoxes in 150 B.C.

EXERCISE II

PROBLEMS TO BE SOLVED BY GLOBES

Object. No chart can give so perfect a representation of the sky as a globe, but the globe has the disadvantage that the observer is looking at the celestial sphere from the outside instead of from the center. Solving a few problems with the globes overcomes this difficulty, and the student finds that a radius of the globe passing through the star on its surface, and extended to the celestial sphere, finds the true star.

Directions. Identify the parts of the celestial globe:

1. The artificial horizon, consisting of the amplitude circle, the azimuth circle, the points of the compass, the signs of the zodiac, the degrees of each sign, the dates of the month.

2. The celestial equator on which the right ascension is reckoned in hours from 1 to 24; the ecliptic on which the signs of the zodiac, each 30°, are marked.

3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

Place	Latitude	Date	Sunrise	Sunset	Length of Day

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.

EXERCISE III

STUDY OF SEASONS BY GARDNER'S SEASON APPARATUS

NOTE. Demonstrations with the apparatus referred to in this and the following exercise should be given by the instructor. Students should record in their notebooks all observations and answers to questions.

Directions. After a description of the apparatus has been given by the instructor, the globe should be separately revolved to show each point.

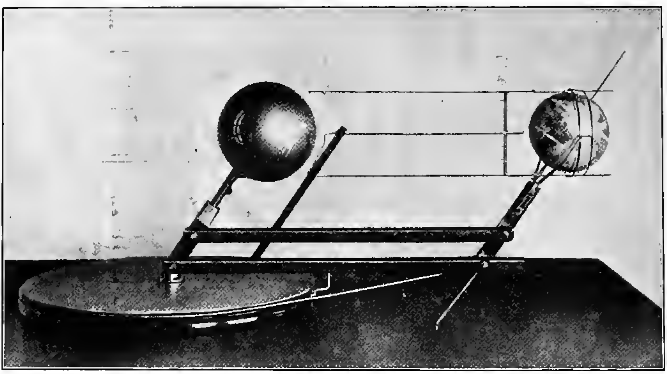

FIG. 1. GARDNER'S SEASON APPARATUS

1. Demonstration of parallelism of axis. Show that in the northern hemisphere in June the axis makes an acute angle with the perpendicular ray from the sun, in September a right angle, in December an obtuse angle, and in March a right angle again.

2. Demonstration of the relation of the circle of illumination to circles of diurnal rotation at the different seasons,

and the consequent length of day and night and amount of heat received.

3. Demonstration of the advance of the oblique ray northward in winter.

4. Demonstration of the tropics and polar circles. The slate globe and chalk may be used for this.

Answer in the notebook the following questions:

1. Towards what point in the sky does the north extremity of the earth's axis point?

2. State the angle which the axis makes with the perpendicular ray from the sun at different times of the year.

3. Define the circle of illumination and state its relation to the circles of diurnal rotation at different times of the year.

4. State when the days and nights are of equal length, and give reasons.

5. State the reason of the long polar daylight and darkness.

6. State the length of the day and of the night at the equator at different seasons.

EXERCISE IV

STUDY OF TWILIGHT BY McVICAR'S GLOBE

NOTE. If the more expensive and elaborate piece of apparatus, the McVicar's globe, is possessed, it can be used for all demonstrations of the parallelism of the axis of the earth and the seasons, but it is especially valuable to show very strikingly the varying duration of twilight from the equator to the pole.

Directions. Set the horizon twilight frame with its zenith over the place it is desired to study (directions accompany the globe); clamp the frame and revolve the globe. It will be seen that in high latitudes the twilight belt at the summer solstice is traversed nearly all night by the sun.

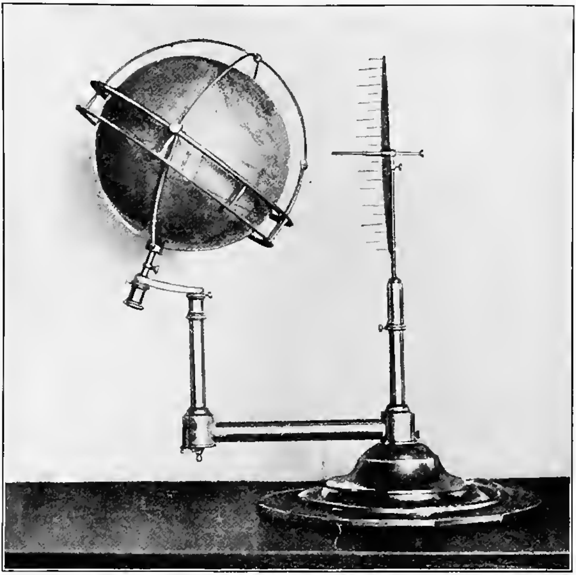

FIG. 2. McVICAR'S GLOBE

In the same way show the shortness of twilight at the equator, on account of the perpendicular path across the twilight belt, and the duration of twilight for months at the pole.

It is especially interesting to set the twilight frame for London or Edinburgh, or places in Norway, and to note the reason for the long summer twilights so noticeable to tourists. The very short twilights in places near the equator remarked by tourists to Cuba or Panama may well be demonstrated.

EXERCISE V

STUDIES WITH THE SEASONAL TWILIGHT CHART

NOTE. This exercise consists of two parts, — drawings by the student, and studies by the use of the chart.

Before any work is attempted by the student the instructor should set up a globe and show how the chart is a projection of the celestial sphere on the meridian, from a point of observation due east in the plane of the horizon. The Sun-path Model, set sideways, shows perhaps even better what is meant by the orthographic projection in the plane of the meridian.

Material. Seasonal Twilight Chart, unruled paper, compasses, protractor, also globe and Sun-path Model.

Directions for drawings. 1. On three sheets of paper make circles fifteen centimeters in diameter. Through the center of each draw two diameters at right angles. Use the protractor to make these diameters perpendicular. Mark the horizontal diameter, which represents the horizon projected in a straight line *HO*; and the vertical one, which is the prime vertical *ZN*. With the protractor measure on the meridian, below the horizon on each side, an angle of 18°, and draw the small circle which is called "the twilight circle."

2. Complete the figure to represent the conditions in different latitudes as follows:

Measure an angle above the horizon on the north, equal to the latitude of the place, and mark it *P*. Through it and the center draw *PP*, the six-o'clock hour circle projected in a straight line.

Measure angles above the horizon on the south, and below on the north, equal to the complement of the latitude, and draw *EQ*, the equator projected in a straight line. Observe the relation *EQ* to *PP*.

Measure on the meridian, both above and below *EQ*, angles equal to the sun's declination at the solstices, namely 23°.5. Draw the diurnal path of the sun at these times. Print in small letters on these diurnal circles the dates when the sun is on them.

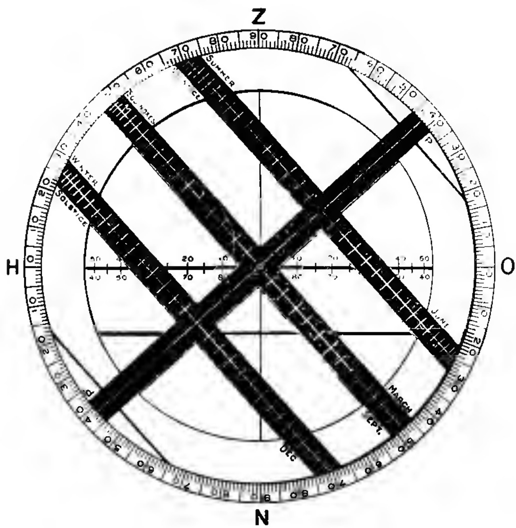

FIG. 3. SEASONAL TWILIGHT CHART

Complete projections for the following latitudes: latitude 72°, the North Cape, within the polar circle; latitude 90°, the pole; the observer's latitude.

Directions for use of chart. With the chart study the following conditions:

1. Latitude 0°, the equator. This will approximately represent conditions at Quito, Singapore, Lake Victoria Nyanza. Note that in these places the north-pole star will be in the horizon.

2. Latitude +23°.5, the northern tropic, near which are situated Havana, Sandwich Islands, Hongkong, Calcutta, Assouan.

3. Latitude 48°.5, nearly the latitude of Paris, Quebec, Vancouver.

4. Latitude 66°.5, the polar circle, near which are Archangel, Iceland, Bering Strait.

Inspect the drawings or the chart and answer the following questions:

1. In latitude 0° how are the twenty-four hours divided?

2. How does the length of day compare with the length of night?

3. How long is twilight at the equinoxes?

4. What is the noon altitude of the sun at the equinoxes? at the summer solstice? at the winter solstice?

5. In latitude 72° what is the length of day at the summer solstice? what is the midnight altitude of the sun? How are the twenty-four hours divided at the equinoxes? at the winter solstice?

6. In latitude 90° discuss the length of day, of twilight, and of night, at the summer and winter solstices and at the equinoxes.

7. What is the sun's altitude in latitude 90° at the summer solstice? How would the sun appear to move that day with reference to the horizon? What would be the form of its path as it gradually sinks to the horizon?

EXERCISES VI, VII, VIII

STUDIES OF THE MOVEMENTS OF MARS, JUPITER, AND SATURN BY MEANS OF GRAPHS

Material. The American Ephemeris, centimeter paper, pencil, centimeter ruler, colored inks, paper centimeter scales or strips cut from the centimeter paper.

Directions for plots. 1. Study the Ephemeris of the planet for the year. Note that the right ascension increases, showing that the planet is moving eastward for some months, but that at a certain date it begins to decrease, showing that the planet has begun to move west or retrograde. Mark on the margin of the Ephemeris the dates of the beginning and end of this retrograde period.

2. Head a page of the notebook "Coördinates of Planet and Ecliptic," and rule five columns.

Date	Jupiter		Ecliptic	
	R.A.	Dec.	R.A.	Dec.

Take from the Ephemeris such coördinates as will place the retrogradation path of the planet in the middle of the sheet. Two dates are enough to take out for each month, except near the turning points.

3. Use a sheet of graph paper lengthwise. Graduate it to a scale in which four centimeters represent twenty minutes of right ascension and five degrees of declination.

4. With a ruler in the left hand to keep the proper right ascension, and a sharp pencil in the right to dot in

the corresponding declination, plot in the points and make through them a smooth fine line with ink. Print in small letters, beside the points, the dates at the beginning of each month.

5. Take out from the Ephemeris the coördinates for the apparent path of the sun (the ecliptic), which corresponds in hours to the path of the planet, and plot it on the graph, using red ink.

6. Take out from the Ephemeris the configurations of the planet for the year in question and record them upon the plot.

7. From the star chart find the most conspicuous stars near the planet, obtain their exact coördinates from a star catalogue, and put them on the graph.

NOTE. These plots should be held above the head toward the south, so that it may be seen that they are a representation of the apparent movements of the planets during opposition. The cause of these movements should be explained.

The above directions are general and will apply to all cases. For convenience, with a large class it is better for the instructor to take out the coördinates to be used and read them to the students, giving directions for the position of the equator on the paper, and for the range of hours in right ascension, and of degrees in declination; also the coördinates of the selected stars.

Inspect the plot just completed and answer the following questions:

1. Is the planet north or south of the ecliptic?

2. Is its latitude increasing or decreasing? Is it approaching an ascending or descending node?

3. How many days did Mars retrograde? Give the date of the middle point of retrogradation. Find the right ascension of Mars on that date, and also of the sun. State the relative positions of Mars and the sun with reference to the earth.

4. What reference stars are most convenient for watching the movements of the planet this year?

5. In what constellation must we look for the planet next year?

Answer the same questions on the graphs of Jupiter and Saturn.

EXERCISE IX

STUDY OF THE MOVEMENTS OF VENUS AS RELATED TO THE SUN—"MORNING AND EVENING STAR"

Directions. 1. Put together lengthwise three sheets of plotting paper.

2. Inspect the coördinates of Venus in the Ephemeris, and note when Venus's retrogradation loop occurs. Take out and tabulate in the notebook such coördinates as will place the loop near the left-hand side of the paper. Make also a list of the coördinates of the sun for the corresponding dates, the first and fifteenth of each month.

3. Graduate the paper to a scale in which each centimeter shall be five degrees of declination and twenty minutes of right ascension. Place the equator in the middle of the paper, and graduate on it the hours of right ascension, also graduate the degrees of declination north and south.

4. Plot in the sun's position, locating each point very distinctly by a red dot, with the date beside it in fine lettering. Connect these positions by a smooth curve in red ink. Similarly plot the path of Venus, marking its positions with black ink dots, the date beside each, and tracing its path in black ink.

5. Cut a narrow strip from the centimeter paper to use as a scale. Write in a table the measured elongation of Venus east or west of the sun for the first and fifteenth of each month.

6. Take out from the Ephemeris the "configurations" of Venus and record them upon the plot.

Questions on the graph. 1. Was Venus east or west of the sun when the plot of its path began?

2. On what date did it pass the sun and become the evening star?

3. In general, on which side of the sun is Venus when it is the evening star? when the morning star?

4. Inspect the table of elongations and state on what date is Venus at the greatest elongation.

5. Find from the table of configurations of the planet when Venus was at superior conjunction, and make a diagram showing in what part of its orbit Venus has been moving ever since.

6. Find from the Ephemeris the date when Venus will be at its greatest brilliancy. Explain.

7. Knowing that Venus shines only by reflected light, what phase does it present at superior conjunction? at inferior conjunction? at the time of greatest brilliancy?

8. Inspect the graph and state the date on which Venus passed ascending and descending node.

9. Measure on the graph the inclination of its orbit to the ecliptic.

10. At what point in its orbit does it retrograde?

The Columbia Planetarium may here be used to advantage. Remove the balls representing the moon and the superior planet, to avoid confusion, and by slowly moving the ball representing the earth show the motions of the earth and Venus, the positions of inferior and superior conjunction, of morning and evening star.

Put on the ball representing a superior planet, and show the positions of the earth and planet at conjunction, at opposition, etc.

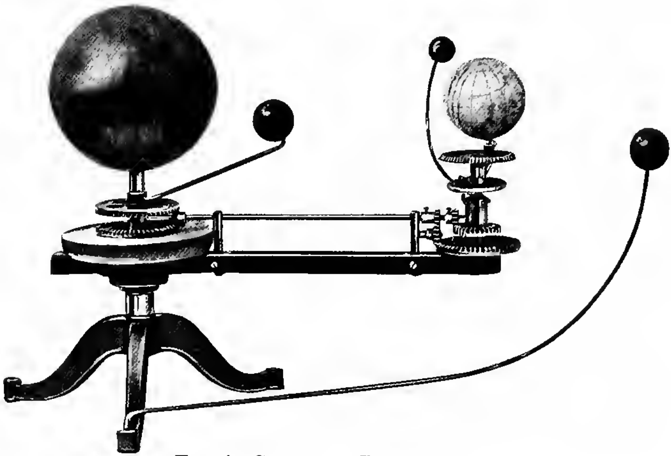

Fig. 4. Columbia Planetarium

EXERCISE X

STUDY OF THE MOON'S MOTIONS DURING A LUNATION

Directions. 1. Take from the Ephemeris the coördinates of the moon at noon each day for the lunation which is chosen. By the proper symbol note on your table of coördinates the time of new, half, and full moon.

2. Put together lengthwise three sheets of plotting paper. As in the Venus plot, graduate to a scale in which each centimeter shall be five degrees of declination and twenty

minutes of right ascension. Place the equator in the middle of the paper and graduate on it the hours of right ascension and also graduate degrees of declination north and south.

3. Plot the sun's path, locating each point very distinctly by a red dot, the first and fifteenth of each month, with the date beside it in fine lettering. Connect these positions by a smooth curve in red ink.

4. Plot in the moon's positions, using each time a small crescent, with its convex side turned toward the sun. Trace the path with black ink, and put in the dates of new, half, and full moon.

5. Using a strip of the paper for a measure of degrees, record in a table the number of degrees traversed each day by the moon. Also in a similar table record the number of degrees traversed by the sun.

Questions. 1. At new moon on which side of the ecliptic was the moon, and what was its latitude?

2. Give the dates at which the moon passed ascending and descending nodes.

3. From this graph show what is the approximate inclination of the moon's orbit to the ecliptic.

4. Inspect the table, giving the number of degrees through which the moon moved each day, and state in what part of the lunation it made the greatest, and also the least, daily progress. What are the names given to the moon's position in its orbit on these dates? Look at the Ephemeris and find the exact dates.

5. Beginning with new moon, on what date did the moon complete a sidereal month, or make a complete circuit in right ascension? How many days in a sidereal month? On what date did the moon complete a synodic

month, or arrive at new moon again? How many days in a synodic month?

6. How many degrees beyond a complete sidereal revolution before new moon? How far then did the sun move in its apparent orbit during this synodic month? Compute the mean distance the sun moves in twenty-nine days, and state how the distance moved this month compares with this mean. Account for this difference. (Is the sun near perihelion or aphelion?)

The Columbia Planetarium may be used to advantage to show the positions of the moon at conjunction, at opposition, etc.

EXERCISE XI

OBSERVATIONS ON THE MOON IN THE SKY

NOTE. These observations must be continued throughout the year, and record made in the notebook to be handed in after each lunation.

Directions. 1. Record the date when you first see the crescent moon in the west. Record also how many degrees north or south from the west point the crescent is seen.

2. Hold up a ruler as a horizontal line, and another ruler or pencil in line with the cusps of the moon. Note the angle which the second ruler makes with the horizontal line. Transfer this angle to the notebook each month.

Fig. 5 shows that the line joining the cusps at the vernal equinox makes an acute angle with the horizon. The figure is made for latitude 42°. Make in the notebook a figure representing the conditions in your latitude; also make a figure representing the conditions at the autumnal equinox.

Use a protractor to make these figures. Show that the old saying, that it is to be a wet or dry month according to the possibility of hanging a pail of water on the crescent, is without meaning, as the position of the crescent for any given month is invariable.

3. Note the position of the moon, with reference to the stars, when first seen, and its position each succeeding

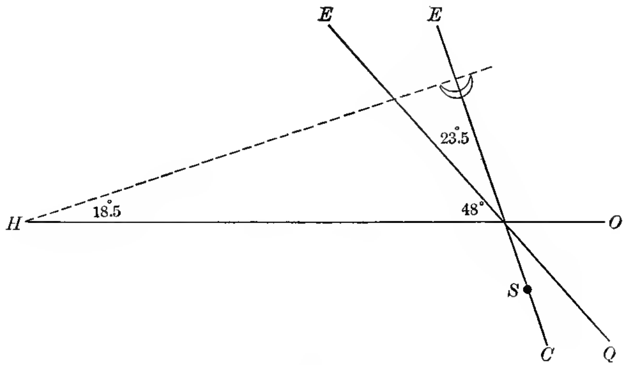

FIG. 5

night. Especially note the dates at which it passes any planets above the horizon. From these observations get a clear idea of the distance through which the moon moves eastward in a day, and of the time it takes for a complete revolution around the earth.

4. Observe during the year the meridian altitude of the full moon, and note that the full moon in winter is where the summer sun is, and that its light is therefore more brilliant than that of the summer full moon.

5. Note the position on the horizon where the full moon rises, that it is always that in which the sun rose six months before.

EXERCISE XII

STUDY OF PHOTOGRAPHS OF THE MOON

Object. To become familiar with the location and characteristics of typical regions on the moon.

Material. Colas's map of the moon (or some other good map), photographs, compasses, ruler, unruled paper.

Directions. 1. Draw a circle with a radius of seventy-five millimeters (this is the largest size convenient on the notebook paper). Draw through the center two diameters at right angles. Mark the top south, the bottom north, the right hand east, the left hand west. The map is to give the appearance of the moon in an inverting telescope. Lay off and mark distances on the horizontal diameter, from the center each way: 73, 70, 64, 57, 48, 37, 25, 12 millimeters. These are the points where the projection of the meridian for each ten degrees cuts the equatorial diameter. Draw meridians through these points and the north and south poles. This can be done fairly well on this small scale by the eye.

2. Sketch in the "seas" from the map, printing the names in small letters.

3. Study each group of photographs displayed. Locate on your skeleton map the most striking features of each region, and record in your notes the results of your study of each photograph: the place at which it was taken, the moon's age, the meridian near the terminator (from the map); whether the moon was waxing or waning; names of the principal mountains from the key; remarks concerning shadows, ridges, white streaks, or peaks which are specially luminous.

For example: Paris photograph. Moon's age, 7.8 days. Terminator, 5° east. Waxing moon. Features: Aristillus, Autolycus, Archimedes, the Apennines, Mare Serenitatis lower left, Mare Vaporum above the Apennines, Manilius left of Mare Vaporum, surrounded by luminous streaks.

4. Finally, make a list of the other photographs of the same region, stating any new features or details observed.

NOTE. Many observatories doubtless possess the superb photographs taken at the Paris Observatory. The most used of these can be backed with cloth and hung on wires about the laboratory for study. The Lick Observatory photographs also are excellent; likewise Ritchie's photographs of selected regions taken at the Yerkes Observatory.

EXERCISE XIII

A STUDY OF THE SUN-SPOT PERIOD BY WOLF'S NUMBERS

Material. A list of Wolf's numbers, loci paper, ruler, and pencil.

Explanation of Wolf's numbers from Monthly Weather Review, November, 1901. In determining the sun-spot activity, Schwabe, its discoverer, counted the spots on the surface of the sun each day, whether isolated or in groups. Wolf, of Zurich, considers the formation of a group of spots more important than the formation of a new spot in a group already existing. He uses the formula $r = 10\,g + t$; that is, the relative number of spots is equal to ten times the number of groups, plus the number of spots. If, for instance, eight spots are arranged in five groups, Wolf's number would be fifty-eight. Wolf's numbers combine the records of different observers reduced to a standard, and begin with 1749.

Directions. 1. Put together lengthwise two sheets of graph paper. Let one centimeter of abscissas represent two years, and one centimeter of ordinates ten of Wolf's numbers. Graduate from the lower left corner of the paper.

2. From the accompanying list of coördinates plot a smooth curve representing the variations of spots on the sun from year to year.

Inspect the graph, and record, in tabular form, answers to the following questions:

1. What are the dates of points of maxima? Find the interval between the maxima, and the mean interval.

2. What are the dates of the points of minima? Find the interval between the minima, and the mean interval.

3. Find the average of the two mean intervals just determined. Of what is this a measure?

4. How many years from each minimum to the succeeding maximum? from each maximum to the succeeding minimum? Find the mean of each of these intervals. How do they compare?

Record any other deductions that you are able to make from the graph.

By continued observation and reasoning all great laws are discovered. Thus Schwabe found the sun-spot period; thus Carrington, who made continued observations for many years, found an equatorial drift in spots and that they begin to appear after a minimum in high latitudes, and die out near the equator.

The nature of sun spots, their relation to solar radiation, and the reason of their periodicity are now being studied at Mt. Wilson Solar Observatory.

WOLF'S NUMBERS

Year	Spots	Year	Spots	Year	Spots
1833	8.5	1856	4.3	1878	3.4
1834	13.2	1857	22.8	1879	6.0
1835	56.9	1858	54.8	1880	32.3
1836	121.8	1859	93.8	1881	54.3
1837	138.2	1860	95.7	1882	59.9
1838	103.1	1861	77.2	1883	63.7
1839	85.8	1862	59.1	1884	63.5
1840	63.2	1863	44.0	1885	52.2
1841	36.8	1864	46.9	1886	25.4
1842	24.2	1865	30.5	1887	13.1
1843	10.7	1866	16.3	1888	6.8
1844	15.0	1867	7.3	1889	6.3
1845	40.1	1868	37.3	1890	7.1
1846	61.5	1869	73.9	1891	35.6
1847	98.4	1870	139.1	1892	73.8
1848	124.3	1871	111.2	1893	84.9
1849	95.9	1872	101.7	1894	78.0
1850	66.5	1873	66.3	1895	64.0
1851	64.5	1874	44.6	1896	41.8
1852	54.2	1875	71.1	1897	26.2
1853	39.0	1876	11.3	1898	26.7
1854	20.6	1877	12.3	1899	12.1
1855	6.7			1900	9.5

EXERCISE XIV

SUN-SPOT ZONES AND PATHS

Material. "Sun-Spot Drawings" by Sestini, or some other sun-spot records, a sheet of tracing paper or architect's linen, a fine pencil.

Directions for use of Sestini's drawings. 1. On a sheet of tracing paper make two circles of the same diameter as those in the drawings, namely about 12.6 centimeters.

2. Lay the left-hand circle so that it coincides with that of the drawing for September 27. Mark the north point. Trace in lightly all the spots.

3. Lay the *same* circle on the drawings for successive days and sketch in all the spots to October 9. You now have a composite of the sun spots between September 27 and October 9.

4. Look back over the plates and connect by fine lines those spots which seem to be identical and to move from left to right. Some spots can be identified for three or four days only, but one travels across the entire disk.

5. Trace on the second circle the drawing following that for November 3, which shows the path of this spot.

Inspect the drawings on the tracing linen and answer the following questions:

1. In what zones of the solar surface do sun spots appear?

2. Are they evenly distributed over these regions, or more crowded north or south of the equator?

3. Mark the position of the north pole of solar rotation, and state how the sun's axis is placed with reference to us.

4. What can you say of the appearance, disappearance, change, and persistence of spots from this study?

5. How do the apparent distances passed over by the spots from day to day compare as they pass from one limb to the other? Account for this difference.

6. If the path of a spot is convex downward in October, what should be the path six months before or after? Compare this phenomenon with the position of the earth's axis at different seasons.

EXERCISE XV

STUDY OF CLUSTERS IN CANCER

Object. To learn the distinction between close and loose clusters, and to become familiar with the location of those clusters which should be included in the program of evening observations.

Material. Plotting paper, ruler, pencil, Roberts's Photographs (Vol. I, pp. 67 and 69), or other photographs of clusters.

Directions. 1. From the list of coördinates given below, taken from Harvard Annals (Vol. XIV), make a chart of the constellation Cancer and locate these two star clusters.

Let one centimeter in abscissas equal five minutes of right ascension, beginning with eight hours; and four centimeters in ordinates equal five degrees of declination, beginning with nine degrees.

2. Note the position of the two clusters. Præsepe is situated between two fourth-magnitude stars, gamma and delta, and two sixth-magnitude stars, eta and theta. The cluster N. G. C.[1] 2682 is near alpha Cancri in the claw of Cancér.

3. Study the photographs of these clusters in Roberts (Vol. I, pp. 67, 69). The photograph of Præsepe was taken with a twenty-inch reflector and exposed ninety minutes. More stars can be photographed than can be seen with the eye in the largest telescopes. Galileo counted thirty-six stars, but the cluster is now known to include about ninety of the seventh, eighth, and ninth magnitudes. A twelve-inch

[1] N. G. C. used above in the designation of the cluster is the common abbreviation for "New General Catalogue."

telescope will include only the stars represented in the center of Roberts's plate.

N. G. C. 2682 consists of over two hundred stars from the tenth to the fifteenth magnitude. It can scarcely be seen in a three-inch telescope.

COÖRDINATES FOR PLOT

Name	Magnitude	R.A.	Dec.
Eta Cancri	6.5	$8^h\ 25^m\ 48^s$	20° 51′
Theta Cancri	6.5	8 24 42	18 30
Gamma Cancri	4.7	8 37 30	21 50
Delta Cancri . . .	4.0	8 39 0	18 31
Cluster Præsepe		8 33 0	19 39
Alpha Cancri	4.2	8 53 0	12 15
Beta Cancri .	3.7	8 11 6	9 30
Cluster N. G. C. 2682		8 49 0	12 45

EXERCISE XVI

STUDY OF STAR CLUSTER MESSIER 13, THE GLOBULAR CLUSTER IN HERCULES

Material. Plotting paper, ruler, pencil, Roberts's Photographs (Vol. II, p. 173) or other photographs, Durchmusterung Chart, Number 21.

Directions. 1. Graduate a sheet of graph paper in right ascension and declination. Let one centimeter in abscissas equal ten minutes in right ascension, beginning with fifteen hours; and let one centimeter in ordinates equal two degrees and thirty minutes in declination, beginning with 10 degrees. Now plot in Hercules and Corona Borealis from the coördinates given below, putting beside each star its proper letter. Put in also the cluster, indicating its position by the proper symbol.

Messier 13 is not visible to the naked eye. Note carefully where you must point the telescope to find it.

2. Identify the stars in this plot on the Durchmusterung Chart, Number 21.

COÖRDINATES FOR PLOT OF POSITION OF MESSIER 13 IN HERCULES (FROM HARVARD ANNALS, VOL. XIV)

NAME OF STAR	MAGNITUDE	R.A.	DEC.
Alpha Herculis	Variable	$17^h\ 9^m\ 12^s$	14° 32′
Beta Herculis .	2.3	16 25 6	21 45
Delta Herculis . .	3.0	17 10 6	24 59
Epsilon Herculis .	3.4	16 55 42	31 6
Zeta Herculis . . .	3.2	16 38 48	31 49
Pi Herculis . . .	3.4	17 10 54	36 57
Eta Herculis	3.4	16 38 48	39 9
Messier 13 . . .		16 37 0	36 30
Epsilon Coronæ . .	4.0	15 52 36	27 14
Delta Coronæ . .	4.5	15 44 36	26 26
Gamma Coronæ . .	4.0	15 37 42	26 41
Alpha Coronæ .	2.0	15 29 36	27 7
Beta Coronæ . .	4.4	15 22 54	29 31
Theta Coronæ . . .	4.0	15 28 6	31 46

NOTE. It is of advantage for the student to make a drawing of this cluster from Trouvelot's Chart or some photograph. He will thus be prepared to observe it with the telescope.

3. Record in the notebook that Messier 13 is the brightest and most condensed cluster in the northern sky. Its angular diameter is from seven to eight degrees. By Bailey's count it is composed of eight hundred thirty-three stars, which can be resolved only by photography. The brightest stars are in a nucleus, from which radiate, somewhat

spirally, six branches of stars, giving the object its resemblance to a crustacean.

4. Study the two photographs in Roberts (Vol. II, p. 173). These were taken with a twenty-inch reflector, exposed sixty minutes and five minutes respectively.

Note that both are taken to the same scale. Therefore the brighter stars in the two pictures are in the same positions, but the photograph of the longer exposure seems to be on a larger scale. State the reason.

EXERCISE XVII

STUDY OF PHOTOGRAPHS OF THE PLEIADES CLUSTER

Object. To learn the names and relative positions of the stars in this familiar cluster, and to study their nebulous surroundings, which photography has revealed.

Material. Plotting paper, ruler, pencil, photographs. The engraved Paris chart found in "System of the Stars" can be used to advantage.

Directions. 1. Make a chart of the Pleiades from the list of coördinates given below.

Let one centimeter in abscissas represent twenty seconds of right ascension, beginning with 3 hours 37 minutes; and let one centimeter in ordinates equal five minutes of declination, beginning with 23 degrees.

2. Put beside each star on the graph its name and magnitude. Learn the name of each, and the relation of the stars in the cluster to one another, so that you may be able to identify each on any photograph or in the sky.

3. Compare your graph with the engraved Paris chart. Sketch in, from this, the nebulosity about each star.

4. Study the following photographs and record notes concerning the characteristics of the nebulosity, the condensations, and any noticeable features.

a. Isaac Roberts, with reflector twenty inches, exposure four hours.

b. Goodsell Observatory, with refractor eight inches, exposure seven hours.

c. Yerkes Observatory, with refractor twenty-four inches, exposure three hours and thirty minutes.

COÖRDINATES FOR PLOT OF THE PLEIADES CLUSTER

NAME	MAGNITUDE	R.A.	DEC.
Alcy′one	3.0	3h 40m 24s	23° 44′
Atlas . . .	3.7	3 42 0	23 41
Elec′tra .	3.8	3 37 48	23 44
Ma′ia . . .	3.9	3 38 42	24 0
Mer′ope	4.2	3 39 12	23 34
Taygeta (ta-ij′e-ta)	4.4	3 38 6	24 5
Pleione (ple-i′o-ne) .	5.1	3 42 6	23 47
Celæ′no . . .	5.2	3 37 42	23 55
Aster′ope	5.7	3 38 48	24 11

EXERCISE XVIII

STUDY OF PHOTOGRAPHS OF DOUBLE CLUSTER IN PERSEUS

Object. To study this cluster in detail; to learn to identify the same stars on different photographs; to measure angular distances on photographs; to locate double stars on photographs.

Material. Roberts's Photographs (Vol. I, p. 39), other photographs, Durchmusterung Chart, Number 25.

Directions. 1. Examine the Goodsell Observatory photograph taken with an eight-inch refractor, with exposure of one hour and twenty minutes. Note the two condensations and the lines and curves of stars.

2. Examine Roberts's photograph (Vol. I, p. 39) taken with a twenty-inch reflector, with three hours' exposure. Compare the photographs, identifying some of the stars. Decide whether one photograph has more stars on it than the other.

3. Measure on Roberts's photograph with a scale, and record in minutes of arc the angular distance between the centers of the condensations. The scale is given in the text opposite the plate.

4. Find, and record in millimeters from the lower left corner, the coördinates of six double stars that you can find on the plate, separated from each other less than twenty-four seconds of arc, that is, less than one millimeter.

5. Find the fiducial stars on Roberts's photograph. Identify them on the Goodsell Observatory photograph, then on Durchmusterung Chart, Number 25.

6. This cluster should be found in the sky. It is a fine type of a loose cluster. In the telescope it shows curves and "festoons" of stars of great beauty. There are two yellow and five red stars. Trouvelot mapped six hundred sixty-four stars.

EXERCISE XIX

STUDY OF PHOTOGRAPHS OF OBJECTS IN THE SOUTHERN SKY

Object. To illustrate methods of measuring photographs in astronomy; to show the effect of prolonged exposure; to show how discoveries of new clusters and double stars can be made by photography; to show the effect of color on photographic magnitude.

Material. Globe, charts of the Uranometria Argentina, or the southern circumpolar map of some atlas, photographs taken at Arequipa, Peru, and published in Harvard Annals (Vol. XXVI), or other similar photographs.

NOTE. The scale of these chart plates is $3' = 1$ mm. The position of any object can be recorded by its x and y coördinates given in millimeters.

1. Examine photographs of Omega Centauri, a globular cluster. Identify the same stars in the different photographs. Measure and record in minutes of arc the diameter of the denser portion of the cluster. Find this cluster on the globe and record right ascension and declination; find it also on the Uranometria Argentina. Observe that it is near the Milky Way.

Record that Bailey found by actual count that there are 6386 stars in a space $30''$ square (eighteen millimeters on the plate).

2. Study of 47 Tucanæ, a globular cluster. Find this object on the chart of the Uranometria Argentina, and record its right ascension and declination. Observe that it is near the small Magellanic Cloud — a detached Milky Way in the southern sky.

Examine, on Plate IX, Fig. 1, exposure two hundred eight minutes; Fig. 2, exposure ninety minutes; Fig. 3, exposure thirty minutes. Why does the cluster appear larger on one plate than on the others, and how is it known that the scale of the plates is the same? Record how many millimeters above the center of the cluster the star A. G. C. 328 is found in each case. This is an 8.75 magnitude star.

3. Study of the region of the Southern Cross. The exposure of this plate was two hours, the scale is 3′ of arc to one millimeter. The plate covers nearly 10° square. Find this constellation on the chart of the Uranometria Argentina. State the latitude of a place in which this asterism would first be seen above the horizon.

Identify the following stars.

	MAGNITUDE	X	Y
Gamma Crucis	1.6	73	173
Delta Crucis	3.1	116	140
Beta Crucis . .	1.5	32	119
Epsilon Crucis . . .	3.5	99	107
Alpha Crucis . . .	1.0	86	53

Do these stars appear of the same relative brilliancy on the plate as their magnitudes would indicate?

Alpha and beta are type 1, delta is type 2, gamma and epsilon are type 3, red stars.

Compare the lower left-hand corner of the plate with the rest for distribution of stars.

4. Find the following clusters by their coördinates.

	X	Y
Kappa Crucis	19	104
N. G. C. 4103	134	89
N. G. C. 4349	92	77

EXERCISE XX

STUDY OF VARIABLE STARS IN CLUSTERS

Object. Professor Bailey of the Harvard Observatory discovered, by comparing photographs of globular clusters taken at different times, that large numbers of variable stars are often to be found in or near them. In this exercise, in which two photographs of the same cluster taken a short time apart are compared, the fact of variability can be noted. To obtain light curve and periods many photographs would be necessary.

Material. Two photographs of Messier 5 in Libra, taken about two hours apart, one set marked *A*, the other set *B*.

Directions. Observe all the marked stars on both photographs, and record whether the photographed image of the star is brighter on *A* or on *B*.

Record in three columns in the following manner:

Number of Star	Chart A	Chart B
1	A >	B

Record that Bailey found by examination of nineteen thousand fifty stars in twenty-three globular clusters, that five hundred nine stars are variable. The period of these stars is short.

Messier 13	among	1000	stars examined gave	2 variables
Omega Centauri	among	3000	stars examined gave	125 variables
47 Tucanæ	among	2000	stars examined gave	6 variables
N. G. C. 362	among	675	stars examined gave	14 variables
N. G. C. 5272	among	900	stars examined gave	132 variables
N. G. C. 7089	among	600	stars examined gave	10 variables
N. G. C. 7099	among	275	stars examined gave	3 variables

EXERCISE XXI

STUDY OF NOVA PERSEI, 1901

Data. Articles in *Popular Astronomy* (Vols. IX and X); photographs of spectra taken on various dates, also photographs of nebulosity. The following coördinates for the light curve are taken from Wilson's table in *Popular Astronomy.*

Date	Mag.	Color and Spectrum	Date	Mag.	Color and Spectrum
Feb. 19	Below 11		Mar. 22	4.29	
Feb. 21	2.7	Blue-white	Mar. 23	3.75	
		Spectrum I	Mar. 24	4.27	
Feb. 22	0.35		Mar. 25	5.31	
Feb. 23	0.00		Mar. 26	3.96	
Feb. 24	0.59	Yellow	Mar. 27	4.13	
		Spectrum II	Mar. 28	4.57	
Feb. 25	1.05	Blue-white	Mar. 29	4.57	
Feb. 26	1.40	Yellow-white	Mar. 30	4.12	
Feb. 27	1.93	Pale yellow	Mar. 31	4.23	
Feb. 28	1.83		Apr. 1	4.11	
Mar. 1	2.34	Yellow	Apr. 2	5.32	
Mar. 2	2.23	Reddish yellow	Apr. 3	5.39	
Mar. 3	2.71	Red	Apr. 4	3.97	
Mar. 4	2.65		Apr. 5	4.28	Yellow
Mar. 5	2.71		Apr. 6	5.39	
Mar. 6	3.05		Apr. 7	4.74	
Mar. 7	3.20	Red	Apr. 8	4.14	Reddish
Mar. 8	3.75		Apr. 9	4.26	
Mar. 9	3.08		Apr. 10	5.48	
Mar. 10	3.26		Apr. 11	5.87	
Mar. 11	3.62		Apr. 12	4.52	
Mar. 12	3.06		Apr. 13	4.51	
Mar. 13	3.61		Apr. 14	5.48	
Mar. 14	3.30		Apr. 15	5.35	
Mar. 15	3.72		Apr. 16	5.94	
Mar. 16	3.75		Apr. 17	4.30	
Mar. 17	3.50		Apr. 18	4.16	
Mar. 18	3.82		Apr. 19	5.53	
Mar. 19	5.05	Spectrum III	Apr. 20	5.57	
Mar. 20	3.15		Apr. 21	6.43	
Mar. 21	4.45				

Directions. 1. For this graph use two sheets of plotting paper pasted together lengthwise. Let one centimeter represent two days in abscissas, and one magnitude in ordinates.

Graduate horizontally from the lower left corner of the paper, beginning February 20, and vertically, beginning with the eleventh magnitude, and continuing upward to zero magnitude.

2. Plot the light curve from the coördinates in the table. Turn the paper sidewise and write opposite the proper points of the graph the color of the star at the dates indicated in the table.

3. Write or print in small letters on the curve, in the same way, opposite the proper dates, changes in spectra by their numbers. Copy on the chart the following descriptions:

February 22. Spectrum I. Orion type. Hydrogen lines broad with color on the red side. The calcium K line also present.

February 24. Spectrum II. Bright and dark lines like those in the spectrum of Nova Aurigæ.

March 19. Spectrum III. Great extension of the ultra-violet lines of hydrogen. II and III alternated, II appearing when the star was brighter, III when the magnitude was below 4.5.

August 24. Spectrum IV. A few bright lines in the green, the spectrum of a gaseous nebula.

4. Finally inspect photographs of the spectra of Nova Persei; also the drawings showing the nebulosity about the central nucleus and its marvelously rapid extension.

EXERCISE XXII

STUDY OF THE MILKY WAY AND OF THE DISTRIBUTION OF NOVÆ, NEBULÆ, AND CLUSTERS

NOTE. If the six-inch globes are not at hand, the star maps and the celestial globe can be used for this exercise; but the white globes are very desirable. After each student has used them the light pencil marks may be rubbed off.

Material. A six-inch globe, ruled with hour circles and declination circles; a protractor.

Data. The position of the galactic circle, or the great circle passing through the brightest part of the Milky Way, is defined thus: north pole, R.A. $12^h\ 47^m$, Dec. + 27°; south pole, R.A. $0^h\ 47^m$, Dec. – 27°; nodes with the equator, $6^h\ 47^m$ and $18^h\ 47^m$, where it crosses the equator at an inclination of 63°.

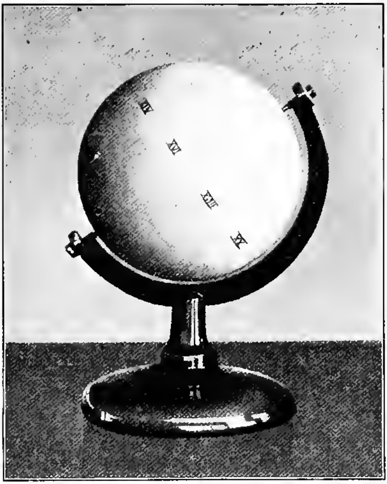

FIG. 6. WILLSON'S ERASABLE GLOBE

The great west branch of the Milky Way begins north $20^h\ 40^m$, + 45°, and extends $14^h\ 30^m$, – 60°. It is about 15° from the main circle at its widest.

From this great circle the relation of objects to the galaxy is measured in galactic latitude and longitude. The starting point for galactic longitude is the point where the 0 hour circle cuts the galaxy in the north.

Approximate places of constellations along the Milky Way are: Cygnus, 20^h, + 40°; Aquila, $19^h\ 40^m$, + 10°; Sagittarius, $18^h\ 30^m$, – 20°; Scorpio, 17^h, – 40°; Norma, 16^h, – 50°; Centaurus, 14^h, – 65°; Crux (in which is the Coal-sack), $12^h\ 30^m$, – 60°; Vela and Puppis, $8^h\ 30^m$, – 40°; Canis Major (west), Argo (east), $7^h\ 30^m$, – 20°; Monoceros, 7^h, – 5°; Taurus (west), Gemini (east), 6^h, + 25°; Perseus, 4^h, + 40°; Cassiopeia, 1^h, + 60°; Cepheus, $21^h\ 30^m$, + 60°.

LIST OF NOVÆ FROM HARVARD ANNALS, VOLUME LVI

Date	Constellation	α	δ	Mag.	Discoverer
		h m			
1572	Cassiopeia . .	0 19	+ 63° 36′	− 5	Lindauer
1600	Cygnus . . .	20 14	+ 37° 43′	3.5	Blaeu
1604	Ophiuchus . .	17 24	− 21° 24′	− 4	Kepler
1670	Vulpecula . .	19 43	+ 27° 4′	3	Anthelm
1848	Ophiuchus . .	16 53	− 12° 44′	5.5	Hind
1860	Scorpius . .	16 11	− 22° 24′	7	Auwers
1866	Corona . . .	15 55	+ 26° 12′	2	Birmingham (spectroscope used)
1876	Cygnus . . .	21 37	+ 42° 23′	3	Schmidt
1885	Andromeda .	0 37	+ 40° 43′	7	Ward (photographs used)
1887	Perseus . . .	1 55	+ 56° 15′	9.2	Fleming
1891	Auriga . . .	5 25	+ 30° 22′	4.5	Anderson
1893	Norma . . .	15 22	− 50° 14′	7	Fleming
1895	Carnia . . .	11 3	− 61° 24′	8	Fleming
1895	Centaurus . .	13 34	− 31° 8′	7	Fleming
1898	Sagittarius .	18 56	− 13° 18′	4.7	Fleming
1898	Ophiuchus . .	17 44	− 16° 40′	7.7	Fleming
1899	Aquila .	19 15	− 0° 19′	7	Fleming
1899	Sagittarius .	18 13	− 25° 19′	8.5	Cannon
1901	Perseus . . .	3 24	+ 43° 34′	0	Anderson
1901	Sagittarius . .	18 0	− 27° 26′	10.4	Cannon
1903	Gemini . . .	6 37	+ 30° 3′	5.1	Turner
1905	Aquila . . .	18 56	− 4° 35′	9.1	Fleming
1905	Vela . .	10 58	− 53° 51′	9.7	Leavitt
1906	Scorpius	17 47	− 34° 20′	8.8	Cannon
1907	Circinus . .	14 40	− 59° 35′	9.5	Leavitt
1910	Sagittarius . .	17 53	− 27° 33′	7.5	Fleming
1910	Ara . . .	16 33	− 52° 14′	6	Fleming
1910	Lacerta . . .	22 31	+ 52° 12′	5	Espin
1912	Gemini . .	6 49	+ 32° 17′	3.5	Enebo

Directions. 1. The hours of right ascension should be marked upon the equator of the globe.

2. Mark upon the globe the north and south poles of the Milky Way.

3. Find on the globe the points at which the galactic circle cuts the equator; place the center of the protractor

on those points, and mark the proper inclination of the galactic circle with reference to its poles. With a light pencil mark sweep the circle around the globe.

4. Mark the points at which the rift begins and ends, and sketch in the western branch one hour circle from the main circle at the widest part.

5. Write in their proper places the names of the seventeen constellations given above, through which the galactic circle passes.

6. Mark by a × the places of all novæ as located by their coördinates.

Inspect the globe and answer the following questions in your notebook.

1. Is there any season in any latitude in which no part of the galaxy would be above the horizon some hour of the night?

2. In what season do those in intermediate latitudes see the most brilliant portion of the galaxy?

3. Can any general statement be made in reference to the position of "new stars" with reference to the galaxy?

4. In *Popular Astronomy* (Vol. XVIII, pp. 545, 546, 547) study the diagrams showing distribution of nebulæ and clusters, and state the relation of these to the galaxy.

EXERCISE XXIII

STUDY OF THE TELESCOPE

Object. To aid the student to get a clear idea of the light-gathering power of telescopes, of the optical principles involved in the achromatic refractor, and of the equatorial mounting.

Directions. Copy on as large a scale as the page of the note-book will permit the drawings below, with brief explanations.

Fig. 7 shows the light-gathering power of a telescope. The parallel lines represent rays of light from the heavenly body. The figure illustrates the varying number of these rays gathered by different telescopes and brought by them to the pupil of the eye. No. 1 brings together fifteen rays to a focus at *E*. No. 2, a refractor, gathers nine rays; No. 3, of less aperture, only three rays.

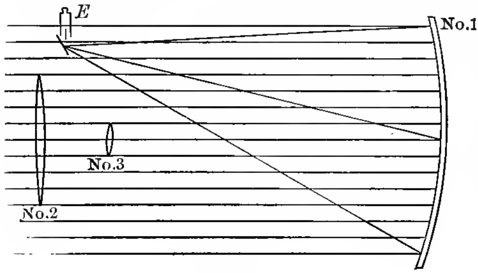

FIG. 7

NOTE. This illustration is but rough. The ratio of the light received into the pupil of the unaided eye is, to that gathered by Lord Rosse's telescope of six feet diameter, as a circle of the diameter one eighth of an inch is to a circle of diameter six feet, or as 1 : 1,000,000. On this light-gathering power of great reflectors depends their ability to show details of such faint objects as nebulæ.

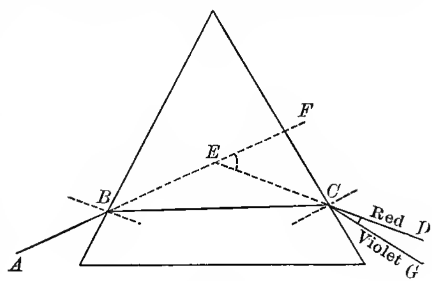

FIG. 8

Fig. 8 and Fig. 9 are drawings to show the necessity for color correction in a telescope. When a ray of white light passes through a medium with inclined sides, as a prism, it is not only bent but dispersed into the colors of the rainbow. The rays of shorter wave length, the violet, are more bent than those of longer wave length, the red.

The ray AB (Fig. 8), after passing through the prism, emerges in a band of color between CD and CG. The angle GCD is the "angle of dispersion," the angle DEF is the "angle of deviation."

We cannot magnify an object without bending the rays, and this bending or refraction of the rays is always accompanied by dispersion into colors.

Uncorrected glasses give a red halo around the image when the screen is within the focus, and a violet halo when the screen is without the focus.

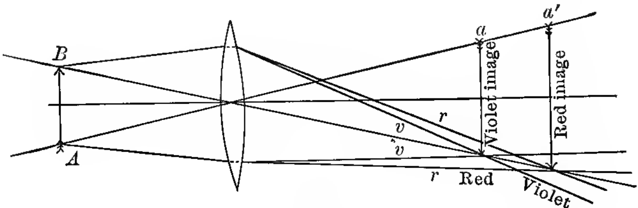

FIG. 9

In Fig. 9 the light proceeding from the object AB is not only bent in passing through the lens, so as to form an image inverted and larger than the object, but is dispersed so that the violet rays cut the axis at v and the red at r. The violet rays from the tip of the arrow come together to form an image on the secondary axis at a surrounded by a red halo, and the red rays at a' surrounded by a violet halo.

It was discovered by Dolland that while flint glass bends the rays about the same amount as crown glass, it disperses about double. A plano-concave lens of flint glass, therefore, with one half the refracting thickness of a double convex lens of crown glass, will, if properly placed, do away with the color fringes.

Fig. 10 is a diagrammatic drawing of the refracting telescope.

A, object glass of flint and crown glass; *F*, the focus to which parallel rays from the distant object are brought; *D*, a "stop" by which the rays coming from the rim of the objective are intercepted; *B*, eyepiece which brings the rays into the eye. A positive eyepiece has the flat side of both lenses out. The reticle of cross hairs should be placed at *F*.

Fig. 11 is a diagrammatic drawing of the equatorial mounting. The equatorial telescope is so mounted that

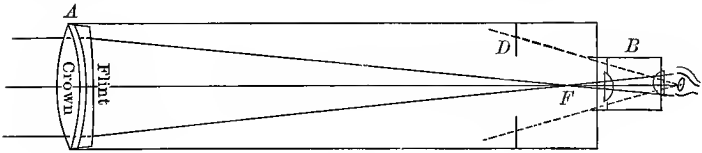

FIG. 10

the observer can easily find any celestial object and keep it stationary in the field.

P, polar axis by which the telescope moves parallel to the equator. This axis must be inclined so as to be parallel to the earth's axis for the given latitude; *D*, declination axis, on which the telescope moves in arcs perpendicular to the equator; *X*, circle on which right ascension is read (this reads 0 when the telescope is in the meridian); *Y*, circle on which declination is read (this reads 0 when the telescope points to the celestial equator); *F*, small telescope called the "finder"; *H*, brace or flexure rod; *L*, *L'*, *L''*, counterpoises.

On setting the telescope on a known star the hour circle registers the hour angle; that is, the difference between the sidereal time and the right ascension of the star. When the telescope is clamped to the clock, it is moved about the polar axis as the hour hand of a watch, at such a rate as exactly to counteract the motion of the earth on its axis.

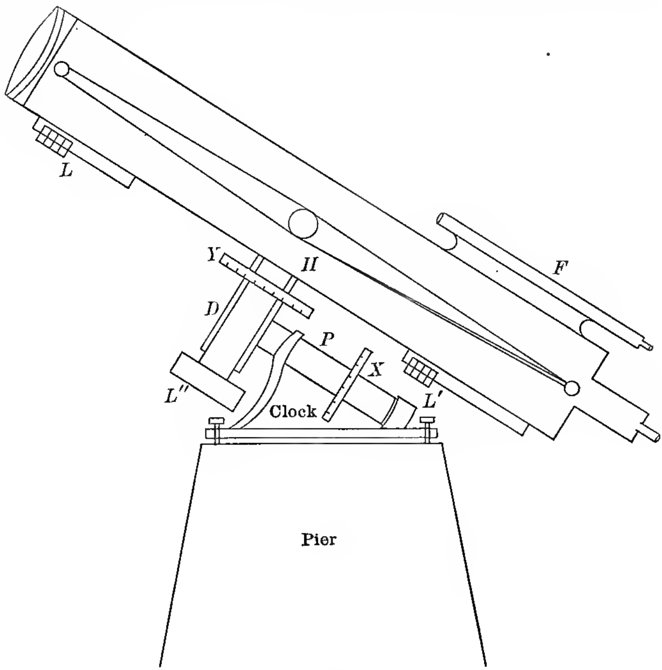

Fig. 11

The clamps and fine adjustments will be shown at the instrument.

The six adjustments of an equatorial telescope are:

1. The polar axis must have an inclination equal to the latitude of the place.

2. The declination circle must read 0 when the telescope is at right angles to the polar axis.

3. The polar axis must be in the meridian.

4. The optic axis must be at right angles to the declination axis.

5. The declination axis must be at right angles to the polar axis.

6. The hour circle must read 0 when the telescope is in the meridian.

NOTE. The method of making these adjustments must be reserved for more advanced work. This exercise should be followed by a daytime demonstration in the dome of the observatory.

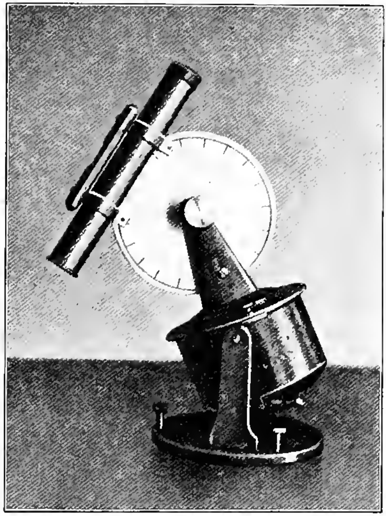

FIG. 12. WILLSON'S EQUATORIAL AND ALTAZIMUTH

Willson's miniature equatorial and altazimuth is a useful piece of apparatus, which, in the absence of a large telescope, can be used to illustrate various methods of mounting a telescope. With this set up in a west window, it is interesting to note the changing azimuth of the setting sun. It can be set in a south window in the fall, and the length of the sidereal day demonstrated by observations upon Fomalhaut.

The sun should be observed by the projection of its image on a screen. For methods of using this instrument as an altazimuth to determine the meridian of a place and the time of apparent noon, or for setting upon a star where adjusted as an equatorial, see Willson's "Laboratory Astronomy."

EXERCISE XXIV

WORK WITH THE SPECTROSCOPE

Object. Our entire knowledge of the chemistry of the stars, of their motion in line of sight, the condition of their atmospheres, depends upon the spectroscope. The spectroscope has made it possible to attack the problem of the life history of a star. Knowledge of the elementary principles of spectrum analysis is therefore essential to any intelligent study of these deeper problems of astronomy.

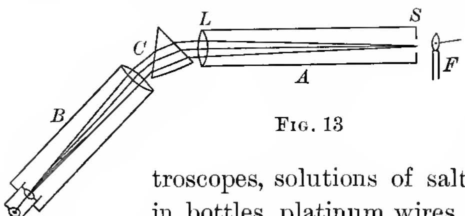

FIG. 13

Material. Prism spectroscopes and direct-vision spectroscopes, solutions of salts of lighter metals in bottles, platinum wires in holders.

Study of apparatus. 1. The prism spectroscope (Fig. 13). *A*, "collimator," with slit *S* at eye end in the principal focus of the convex lens *L* at the other end, so that rays may strike the prism parallel; *B*, telescope or "view tube" attached to a circular scale or with scale in the eyepiece; *C*, prism placed at minimum deviation; *F*, place of Bunsen burner or spark.

Adjustments. Focus the telescope on some distant object, so that it is adjusted to parallel rays; then place the collimator in line with the telescope and adjust the slit until it is seen with sharp edges without changing the telescope. (We know by this that the slit is in the principal focus of the collimating lens.) Next, burn sodium in the flame and adjust the width of the slit, placing the prism at the angle of minimum deviation.

2. The direct-vision spectroscope (Fig. 14).

Fig. 14, *FFC*, prisms of flint and crown glass so placed that the bending of the rays is compensated while the dispersion is permitted. This is the opposite of the thing accomplished by the achromatic lens. *S*, the slit partly covered by a reflecting prism so that two spectra may be compared.

Adjustment. Look at a white cloud, and draw the eye-piece in and out until the edges of the slit are sharp. Then close the slit until the principal Fraunhofer lines appear sharply defined.

3. Apparatus for observing the spectra of gases or metals heated by the electric spark. This apparatus consists of some source of electricity, an induction coil or "step-up transformer" to convert the current into electricity of high tension, and Plücker tubes containing the gases to be observed, or a spark apparatus.

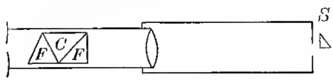

Fig. 14

4. A simple arrangement by which a "normal spectrum" may be observed consists of a pasteboard tube with a slit at one end and a grating held before the eye, or an Ives simplex normal spectroscope.

The following observations are to be taken, not necessarily in the order here given, and brief notes recorded.

1. With pasteboard tube or normal spectroscope directed toward the sky, observe the normal spectrum. Note that this consists of a white image of the slit, with three or four orders of spectra on one or both sides. Each spectrum has the violet nearest the slit, and the colors — blues, greens, reds — occupy about the same space.

2. With the direct-vision spectroscope directed toward the sky, and the slit wide open, observe the prism spectrum of sunlight and note that the blues are relatively more stretched out.

3. Close the slit more, and note, after careful focusing, the Fraunhofer lines or gaps, beginning at the red end, *C*, *D*, *E*, *b*, *F*, *G*. Compare what you see with the colored chart.

NOTE. The *C* and *F* lines are due to the absorption of hydrogen, the *D* to that of sodium. The *E* and *b* lines are shown by a larger spectroscope to be groups of lines partly due to calcium. All this absorption takes place in the sun's atmosphere, ninety-three million miles away.

4. Open the slit wider, so that the Fraunhofer lines are no longer seen, and place before it, in turn, bottles containing copper sulphate, bichromate of potash, chlorophyl, didymium. Note the wide absorption gaps and record in what part of the spectrum they appear.

5. With the spectrometer observe the spectra of the following substances volatilized in the Bunsen flame: Na, Li, Tl, Sr, Ba. The electrons of these substances, freed by the heat to vibrate in their characteristic way, give out waves to the ether selectively; that is, they show a spectrum of bright lines here and there of different wave lengths.

6. With the apparatus for observing the spectra of gases, observe the spectrum of H, He, N, C. Observe that the spectrum of nitrogen is much more crowded with lines than hydrogen or helium. Carbon shows a banded spectrum like that of comets and fourth-type stars.

7. *Charting spectra.* Prepare in the notebook with a millimeter scale strips similar to those on the large colored

chart of Kirchhoff or the colored chart in Ganot's Physics, and copy from that chart, or from the table below, the spectra of the substances observed. Color the lines with colored crayons.

TABLE GIVING IN MILLIMETERS FROM THE LEFT THE POSITION OF LINES FOR CHARTING SPECTRA

Sun, 17.5, 28, 34, 50, 71, 75.5, 90, 107.5.
Hydrogen, 34, 90, 127.5.
Sodium, 50.
Lithium, 32.
Thallium, 68.
Strontium, 30, 32.5, 35, 36.5, 38.5, 42, 46, 105.
Calcium, 42, 46, 49, 52, 55, 61.
Barium, 40, 46.5, 50.5, 61, 67, 72, 77.5.

8. The reversal of the sodium line with Willson's apparatus. In this apparatus a Nernst glower is a source of intense white light, which is analyzed by a simplex normal spectroscope. A wood-alcohol lamp is interposed, in whose cooler flame a platinum wick dipped in salt solution is held. A stop cuts off the Nernst light from half the slit, so that the yellow sodium line appears, and below it the dark absorption line, the "D line" of the solar spectrum.

This repetition of the crucial experiment of Kirchhoff is highly desirable, as it furnishes the key for the interpretation of all stellar spectra.

The following principles for the interpretation of spectra have been established by a long line of distinguished investigations:

1. Incandescent solids and gases at enormous pressure, in which vibrating electrons cannot move without frequent collisions, give out a continuous spectrum of light of all wave lengths.

2. Incandescent vapors under low pressure, in which vibrating electrons can move in their characteristic way, give out discontinuous spectra of bright lines or give out light selectively.

3. *Kirchhoff's principle.* Every vapor at lower temperature will absorb light given out by the same at higher

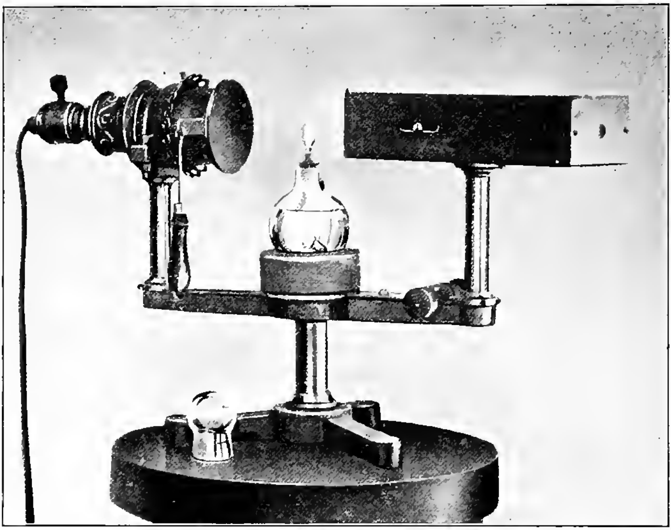

FIG. 15. WILLSON'S SODIUM-LINE REVERSER

temperature. If white light be transmitted through vapors at lower temperature, it will be deprived of the wave lengths characteristic of each vapor. It will give a broken spectrum.

4. A widening of lines in general indicates that the source of light is undergoing pressure.

5. *Doppler's principle.* A displacement of lines toward the red end of the spectrum indicates that the source of

light is receding; a displacement toward the blue, that the source is approaching.

6. A coincidence of reversed lines in the spectrum of sun or star, with bright lines obtained from some element in the laboratory, indicates the presence of that element.

7. *Zeeman's principle.* If a source of light is placed in a magnetic field, the simple lines of its spectrum will be resolved into triplets or more complex forms.

EXERCISE XXV

USE OF CLOCKS

Clocks are of two kinds:

1. Those which keep sidereal time; that is, the actual time of the earth's rotation. These "sidereal clocks" begin the day, $0^h\ 0^m\ 0^s$, at what is called "sidereal noon," the instant when the vernal equinox crosses the meridian. They are graduated into twenty-four hours.

2. Those which keep "mean time"; that is, which mark noon when the fictitious sun crosses a certain meridian. They may keep

a. Local mean time; that is, mark noon when the fictitious sun crosses the meridian of the place.

b. Standard time; that is, mark noon when the fictitious sun crosses the standard meridian.

c. Civil mean time, which begins the day at midnight.

d. Astronomical mean time, which begins the day at noon.

Description of clocks at Whitin Observatory.[1] 1. The sidereal clock is by E. Howard & Co. of Boston. It has a mercury-compensation pendulum, in which four tubes of mercury

[1] The clocks in use in any school or observatory should be thus described.

form the bob. The expansion of the mercury upward with higher temperature preserves the length of the pendulum constant by keeping the center of oscillation at the same point.

The clock has what is called "a four-legged gravity escapement." It ticks seconds and makes an electrical contact every second, omitting the fifty-ninth. It is made to gain or lose by changing the length of the pendulum. One turn of the micrometer screw, which lengthens or shortens the pendulum, changes the rate of the clock thirty-three seconds in twenty-four hours, or 1.4 seconds an hour.

2. The chronometer is by William Bond & Son of Boston. It ticks the half second and can be made to break an electrical circuit every half second.

To compare the clock and chronometer, set down the time of the clock at the end of some minute, and before the minute is up, with eye on the chronometer, listen to the ticks of the clock, and at the sixtieth tick note the time on the chronometer to the half second. Thus take four or five observations at intervals.

Then reverse, and read the clock at the last tick for the minute of the chronometer.

For a calculation of the comparative rates of the clocks, more observations are needed than students could well take; therefore, from the accompanying list, find how much the clock is gaining on the chronometer each hour.

Date	Clock	Chronometer	Interval	Hourly Gain
Aug. 18	$2^h\ 23^m$	$7^h\ 17^m\ 41.5^s$		
Aug. 19 . . .	2 23	7 13 59.5		
Aug. 20 . .	2 28	7 15 17		
Aug. 21 . . .	3 7	7 50 29		

Use of clock to tell the precise time of some event. In watching the passage of a star across the field of a transit instrument by the "eye-and-ear method," the observer wishes to record the precise time of the star's crossing each wire of the reticle (Fig. 16). This requires the doing of several things at once — watching for the bisection of the star by the wire, listening and counting the ticks of the clock, and putting down the second of passing the wire.

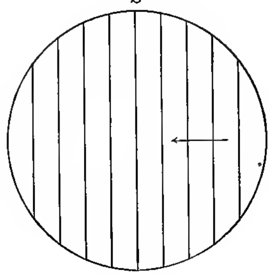

Fig. 16

Practice[1] may be given by recording the time of a series of taps and finding the interval between them.[2] Let one tap with a piece of wood while others listen for the ticks of the chronometer, and put down the second of the tap. Practice until it can be correctly done. Record in columns headed as follows:

Time of Taps	Intervals

[1] Facility in all evening observations is gained by a thorough study of the instruments and methods in the daytime. Practice with the transit, clock, and chronograph may be gained by using a chronograph to find the time of the beat of a metronome to the tenth of a second.

[2] See Comstock's Astronomy.

EXERCISE XXVI

USE OF CLOCK TO FIND ANGULAR APERTURE

Object. It is desirable to know the area of the sky which is included in the field of the different oculars of different telescopes. Since the earth turns on its axis one degree in four minutes of time, if an equatorial star is allowed to trail across the field by the earth's motion, and the exact time of the passage is found and converted to angular measure, it gives the angular diameter of the eyepiece.

Directions. Let one observer set the telescope so that a selected star is just out of the field on the following, or right-hand side, while another observer prepares to read the chronometer. When the star just enters the field let the observer at the telescope say "now," and the clock be read. When the star is nearly off the field, let him say "ready," and when it disappears "now," and let the clock be read.

Record in tabular form and convert the time to arc, remembering that

4 minutes of time = 1° of arc
1 minute of time = $15'$ of arc
1 second of time = $15''$ of arc

In this manner find the aperture of the finder and of the different eyepieces of the telescope.

Take the mean of three observations, the observer and time recorder changing places.

NOTE. The mean-time chronometer can be read to half seconds, and for a short interval serves for sidereal time. If the star is near the equator, the correction which can be made by mathematical methods is negligible.

Next make a diagram to show the areas covered by different oculars as follows:

On a scale of one minute to a millimeter construct concentric circles showing the comparative areas of the sky covered by the eyepieces measured.

The "finder" covers a comparatively large area of the sky, and when an object is in the center of it, it is in the center of the field of higher powers.

It can also be seen why objects are so soon out of the field of higher powers.

EXERCISE XXVII

USE OF SIDEREAL CLOCK TO SET THE TELESCOPE ON ANY OBJECT

Directions. 1. Look up the right ascension and declination of the object in some catalogue or in the Ephemeris. Make correction for precession if necessary.

2. Set the declination circle on the declination given and clamp it.

3. Find the hour angle of the body by subtracting the sidereal time from its right ascension, if it is *east* of the meridian; by subtracting its right ascension from the sidereal time, if it is *west* of the meridian. Set the telescope to this hour angle at the instant the sidereal clock is on the time. The object should be in the middle of the field.

NOTE. A list of objects in good position for observation will be given out by the instructor. Allowance must be made for errors of the circles. It is best to calculate the hour angle a few moments ahead, to give time to set the telescope.

EXERCISE XXVIII

TO FIND THE ERRORS OF THE CIRCLES OF THE EQUATORIAL

Directions. 1. Select some almanac star near the meridian. Look up its coördinates in the Ephemeris.

2. Set the cross hairs of the finder of the telescope on the object. Clamp the declination circle and read it. The difference between the reading of the circle and that given in the Ephemeris is the error of the declination circle.

3. Using the correct sidereal time, calculate the hour angle of the star at a selected moment ahead, and at that moment let one observer keep the star on the cross hair while another reads the circle. The difference between the calculated and the observed reading is the error of the hour circle, plus or minus.

NOTE. The sidereal clock is corrected by observations with the transit. Its error should be found on a card near the clock.

EXERCISE XXIX

READING SIDEREAL TIME BY CAPH

The sidereal day begins at any place when the vernal equinox, or any star on the equinoctial colure, makes its upper culmination. The sidereal clock then reads $0^h\ 0^m\ 0^s$. From this instant the sidereal day is reckoned through twenty-four hours. Beta Cassiopeia (Caph) is almost on this colure and only thirty-two degrees from the north pole, so that it is always above the horizon in intermediate latitude. Therefore when this star, sometimes called the "clock hand of the northern sky," makes its upper culmination the sidereal day begins.

The star moves in the opposite direction to the hands of a watch, and only half as fast.

Directions. Estimate the sidereal time by the direction of Caph from the pole star. When it is at upper culmination the time is 0^h, when west 6^h, when at lower culmination 12^h, when east 18^h. The intervals between these points can be estimated. Read the sidereal clock when possible, or calculate the sidereal time from the Ephemeris and standard chronometer. Record in your notebook at least four observations under the following heads: Date and Hour; Estimated Sidereal Time; Sidereal Clock Time; Error.

EXERCISE XXX

PRACTICE IN ESTIMATING DEGREES ON THE CELESTIAL SPHERE

Directions. 1. Familiarize the eye with the following standard distances:

The diameter of the moon is 0°.5.

The distance between Megrez and Dubhe is 10°.

The distance between Castor and Pollux is 4°.5.

The distance from Polaris to Caph is 28°.5, Caph to Sirrah is 30°.

2. Write in your notebook your estimate of the following distances: between stars in the "great dipper," beginning with the end of the handle; between stars in the base of the "little dipper" of Ursa Minor; between stars in the "chair" of Cassiopeia; between stars in the "head" of Draco; between stars in the "triangle" of Lyra; between stars in the "cross in the Milky Way."

EXERCISE XXXI

ESTIMATION OF BRIGHTNESS OF ALGOL AT DIFFERENT TIMES BY ARGELANDER'S METHOD

Directions. Use as comparison stars three of this list of stars of not very different brightness: gamma Persei, alpha Persei, zeta Persei, tau Persei, delta Persei.

For convenience in recording let v represent Algol.

Look directly at Algol until you have a distinct impression of its average brightness, freed from momentary changes due to atmospheric disturbance. Then observe the second star in the same manner, and so on, alternating, each observation lasting a few seconds.

If the two stars appear equal after a careful examination, or if the comparison star seems greater than the variable as often as the variable appears greater than the comparison star, then put down $v =$ alpha.

If one is suspected to be brighter — that is, if it appears after several comparisons more frequently brighter than fainter — then the interval may be designated one grade, and the observation recorded $\alpha\, 1 > v$ or $v\, 1 > \alpha$, the brightest first.

If one star is certainly brighter, the difference, however, being very small, the difference will be two grades: $\alpha\, 2 > v$ or $v\, 2 > \alpha$. (A grade thus estimated will slightly exceed one tenth of a magnitude.)

The difference is three grades when the estimate is always $\alpha > v$, and yet hardly larger than necessary to prevent writing $v > \alpha$.

Compare and record in columns five observations of Algol with three stars. Note the day and hour, and on as many other evenings as possible make independently the same comparisons.

Write out conclusions in reference to the light of Algol.

It is desirable to find from some astronomical journal the evening when a minimum occurs, and to take observation on that evening as often as possible, to find the exact time of the minimum.

Beta Lyræ may be observed in the same manner.

EXERCISE XXXII

DETERMINING STELLAR MAGNITUDE BY GRADES

Directions. Take for comparison stars alpha Ursæ Minoris (Polaris), 2.2 magnitude; and gamma Ursæ Minoris, 3.0 magnitude. Find by the method described in the previous exercise the magnitude of six stars in the neighborhood; as, beta, delta, zeta Ursæ Minoris, 51 Cephei, eta and zeta Draconis.

EXERCISE XXXIII

PREPARATION FOR CONSTELLATION STUDY

Directions. The identification of the stars and constellations in the sky is greatly aided by daytime study of star maps. The following studies give the "catch figures" formed by the brightest stars of each constellation. These should be found on the star map and carefully outlined in pencil. Familiarity with these figures makes it possible to recognize easily the stars in the sky, and outlining them on the maps to turn quickly to the one desired.

After finding the objects which can be seen with the naked eye, a field glass will reveal much more of interest and beauty.

NOTE. Thorough familiarity with the Greek alphabet is necessary at the start. The names of the Greek letters, which are spelled in the text, will appear on the map in symbols only.

THE GREEK ALPHABET

Letter	Name	Letter	Name
α	alpha	ν	nu
β	beta	ξ	xi
γ	gamma	ο	omicron
δ	delta	π	pi
ε	epsilon	ρ	rho
ζ	zeta	σ	sigma
η	eta	τ	tau
θ	theta	υ	upsilon
ι	iota	φ	phi
κ	kappa	χ	chi
λ	lambda	ψ	psi
μ	mu	ω	omega

CONSTELLATION STUDY FOR SEPTEMBER

Northern Circumpolar Constellations

Ursa Major. Catch figure, the "great dipper" of second- and third-magnitude stars, which marks the body of the bear. Merak and Dubhe are called the "pointers," since a line drawn through them and prolonged toward the pole nearly passes through the north star.

A triangle with curved sides leads to the nose — Dubhe or alpha, *h*, *o*, upsilon, Merak or beta.

Three pairs of third- and fourth-magnitude stars mark the paws — nu, xi; mu, lambda; and iota, kappa.

Above the triangle marking the nose, with the field glass find two groups of fifth-magnitude stars — sigma 1 and sigma 2, and pi 1 and pi 2.

Ursa Minor. Catch figure, the "little dipper." The handle, a curve concave toward the "great dipper," consists of Polaris and three fourth-magnitude stars; then Kochab or beta, and gamma, form the bottom of the bowl, and eta, a fifth-magnitude star, completes the figure.

Draco. A trapezium of second-, third-, and fifth-magnitude stars marks the head of Draco: beta, gamma, xi, nu. The first coil is marked by a pentagon of second- and fourth-magnitude stars — phi, chi, tau, epsilon, delta. The tail curves between the two dippers — zeta, eta, theta, iota, Thuban or alpha, kappa, lambda.

Cepheus. Catch figure, a pentagon of fourth-magnitude stars, partly in the Milky Way — alpha, iota, gamma, kappa Cephei, and delta Draconis. Beta Cephei is in the middle of the pentagon. A little triangle of the fourth-magnitude stars in the Milky Way marks the head.

Cassiopeia. Catch figure, a W in the Milky Way — Caph or beta, alpha, gamma, delta, epsilon.

With the field glass observe that this constellation is everywhere rich in clusters and groups of stars.

Perseus. The "bow in Perseus" is in the Milky Way — delta, alpha, gamma, eta. (In the center of an equilateral triangle, consisting of alpha, Algol or beta, epsilon, was the nova of 1900.) By comparing, for a succession of nights, the light of Algol, or beta Persei, with alpha, Algol will be seen to be a variable star.

With the field glass look at the double cluster in the sword handle between the "bow in Perseus" and Cassiopeia, which can be faintly seen with the naked eye. Sweep from this cluster toward Andromeda and find clusters.

Andromeda. Catch figure, a great diamond — Algol, beta Trianguli, Mirach or beta, and Alamak or gamma

Andromedæ. A curve — beta, mu, nu — marks the girdle of Andromeda. Parallel to the girdle, zeta, delta, pi, theta, mark the arms and shoulders. Near nu is the "great nebula."

Sirrah, or alpha Andromedæ, is in the "great square" in Pegasus.

Constellations of the Zodiac

Note. Beginning at right ascension eighteen hours, the place of the sun at the winter solstice, the following constellations are seen in the autumn.

Sagittarius. Catch figures: a small "dipper" in the shoulders — zeta, tau, sigma, phi, lambda; the "bow" — eta, epsilon, delta, lambda, mu; the "arrow" — delta, nu.

With the field glass sweep near lambda and find clusters Messier 24 and Messier 25, and rich fields of stars. East of dipper are several pairs.

Capricornus. East of Sagittarius find a close pair of stars, alpha and beta Capricorni. Below this pair trace a trapezium of third- and fourth-magnitude stars — theta, psi, omega, zeta; and a triangle — zeta, epsilon, delta, gamma, iota, theta.

With the field glass find cluster Messier 30 east of zeta. Alpha Capricorni is double, consisting of two fourth-magnitude stars.

Aquarius. A triangle with a star in the middle marks the "waterpot of Aquarius" — gamma, eta, zeta, pi. This group is on the equator.

West of this a large triangle — alpha, beta, theta — and a trapezium — theta, lambda, iota, delta — mark the body of Aquarius.

From the "waterpot" a stream of fourth- and fifth-magnitude stars mark the stream of water, ending at a white first-magnitude star, Fomalhaut, in the constellation Piscis Australis.

Above mu and epsilon, with the field glass, find assemblages of stars.

Pisces. Catch figure, a pentagon of fourth- and fifth-magnitude stars — iota, theta, gamma, kappa, lambda. These stars mark the location of the western fish.

Just east of this, and a little below, is the vernal equinox, the place of the sun on March 21, and the starting point for celestial measurements.

The ribbon which joins the western to the eastern fish is marked by iota (in the pentagon), omega (a fourth-magnitude star), then delta, epsilon, zeta, mu, nu, xi. Alpha, a fourth-magnitude star, marks "the knot." Then northwest are omicron, eta, and an irregular group of fifth-magnitude stars which marks the eastern fish.

Constellations of the Milky Way

Sagittarius, already described as a constellation of the zodiac.

Aquila and Antinous, Sagitta, Delphinus, Vulpecula. Find first a line of three stars which marks Aquila — beta, alpha, gamma. Altair, or alpha Aquilæ, is a first-magnitude star. Find below a double triangle which marks Antinous — theta, eta, delta, iota.

Above Aquila find three fourth-magnitude stars and a pair of stars in a line at right angles to the line which has Altair in the middle. This is Sagitta.

East of Aquila and Sagitta find Delphinus, a little trapezium of fourth- and fifth-magnitude stars.

Above Delphinus and Sagitta the group of fifth-magnitude stars form Vulpecula.

The western stream of the Milky Way passes through Hercules and Ophiuchus, to be described later.

A glass reveals myriads of stars not visible to the eye, also clusters and close assemblages.

Cygnus. Catch figure, the "cross in the Milky Way": alpha, gamma, eta, chi, beta, the long arm of the cross; and epsilon, gamma, delta the short arm.

61 Cygni, a sixth-magnitude star, the nearest to us in the northern sky (a yellow star and double in the telescope), is found by tracing a trapezium (rho, xi, nu, sigma) and a triangle (nu, psi, sigma). Halfway between nu and psi is the sixth-magnitude star 61 Cygni.

With the field glass sweep from beta Cygni halfway to the two stars zeta and epsilon in Aquila, and note a lovely group, "six stars in a row with a garland hanging from the center." In the angle of the cross (alpha, gamma, delta) find a pair of stars (omicron 1 and 2). Sweep with the glass about alpha and gamma for fine fields.

Lyra. Catch figure, an equilateral triangle formed by Vega or alpha Lyræ, a first-magnitude bluish star, and two fourth-magnitude stars, epsilon and zeta. From delta make two triangles — delta, beta, gamma; and delta, eta, theta.

With the field glass look at epsilon and find it double (with telescope each component is double). Look at delta, which is fourth-magnitude, and see a fifth-magnitude companion. Look at gamma and find fifth- and sixth-magnitude stars in the neighborhood. Compare often the light of beta with gamma, and find beta a variable star. (Halfway between beta and gamma is the annular nebula, which can be seen only with a large telescope.)

CONSTELLATIONS NORTH OF THE ZODIAC AND EAST OF THE MILKY WAY

Pegasus. Catch figure, the great "square in Pegasus"— Sirrah or alpha Andromedæ, alpha, beta, and Algenib or gamma Pegasi.

From alpha trace a curve of stars just above Aquarius, and convex downward. This curve marks the neck and head of the horse, ending in the second-magnitude star epsilon.

From beta trace a line (beta, eta, pi) marking one leg of the horse.

With the field glass sweep the region inclosed in the square and see many faint stars; look at pi and note that it is double.

Equuleus. A small region west of Pegasus and north of Aquarius. A fourth-magnitude star, alpha Equulei, is the brightest star in this little constellation.

Cetus. A trapezium of fourth-magnitude stars (zeta, theta, eta, tau) marks the body of Cetus. Connect to this a triangle — eta, tau, beta (second magnitude) — which marks the tail of Cetus. The head is marked by a curve of third- and fourth-magnitude stars—alpha, mu, xi 1 and 2, alpha Piscium.

A triangle is formed by alpha Piscium, delta Ceti, and the remarkable variable star, omicron Ceti or Mira. Mira is not always visible.

GREAT CIRCLES TRACED AMONG THE STARS

The equator, beginning west, passes just below the little triangle which ends the west branch of the Milky Way, below Altair, through the triangle which marks the "water-pot" of Aquarius, just below the pentagon in Pisces, and the star alpha Piscium, which marks the turn in the "ribbon" of Pisces.

The ecliptic, beginning west, passes just above the "dipper" in Sagittarius, through the trapezium in Aquarius, just above lambda, below the pentagon in Pisces.

The equinoctial colure, or first hour circle of the. heavens, beginning north, passes near Megrez (the star at the junction of the "bowl" and "handle" of the "great dipper"), through Polaris, Caph, Sirrah, Algenib. Thirty degrees below Algenib, near the pentagon of Pisces, is the vernal equinox.

CONSTELLATION STUDY FOR DECEMBER

Constellations of the Zodiac seen in Winter

Note. This study begins at about 1 hour and 40 minutes right ascension, approximately the place of the vernal equinox in the time of Hipparchus.

Aries. Catch figures, a triangle of second- and third-magnitude stars, marking the head of the ram — alpha, beta, gamma; also a large trapezium — alpha, gamma, delta, *c*.

Taurus. The brighter stars of the loose cluster called the Hyades make a V — Aldebaran or alpha (a first-magnitude red star), theta 1 and 2, gamma, delta, epsilon. (Aldebaran is sometimes called the "eye of the bull.") Above the Hyades are the Pleiades, a group of fourth-magnitude stars.

Following the line of the two prongs of the V, find beta and zeta, second- and third-magnitude stars, sometimes called the "horns of the bull."

Below the Hyades trace a lengthened pentagon of third- and fourth-magnitude stars in the shoulders of the bull — mu, lambda, xi, omicron, nu.

Use the field glass and note the large number of fifth- and sixth-magnitude stars in the neighborhood of the Hyades. Southeast of Aldebaran find sigma 1 and 2, fifth-magnitude stars 7′ apart. Some keen eyes can divide theta 1 and 2, which are 5′.5 apart.

Look at the Pleiades and count the stars in the field. With the field glass find near zeta streams of stars and the "crab nebula," or Messier 1.

Gemini. Find the pair of bright stars, Castor, or alpha, and Pollux, or beta.

Find two lines of stars nearly parallel to the line joining Castor and Pollux: lambda, zeta, epsilon, marking the knees of the twins; and xi, gamma, eta, marking the feet.

With the field glass examine the region about Castor and Pollux, and notice groupings of small stars; examine also the region about the feet. Especially look near eta and mu and note streams of small stars, also several clusters, one of them Messier 35.

(The summer solstice, or the place where the sun is found on June 22, is near this cluster, and here Herschel discovered the planet Uranus in 1781. Since that time the planet has made nearly one revolution and a half about the sun, and is (1912) in constellation Sagittarius.)

Other Winter Constellations

Auriga. Catch figure, a large pentagon of bright stars — beta Tauri (one of the horns of the bull), iota Aurigæ, Capella or alpha, beta, theta. Below Capella find an isosceles triangle of second- and fourth-magnitude stars (the Kids).

With the field glass examine the region within the pentagon, especially above El Nath or beta Tauri. Three clusters are visible to the naked eye and the glass reveals many stars.

Eridanus. Find a stream of third- and fourth-magnitude stars below Taurus. Find two small triangles — lambda, beta, omega; and also omega, mu, nu. Find a curve — gamma, delta, epsilon, zeta, eta.

With the field glass look at omicron 1 and 2; also near eta for rho 1, 2, and 3.

Orion. Find the "belt of Orion" — zeta, epsilon, delta. At right angles to this row of stars, and below, find the "sword" — three third- and fourth-magnitude stars.

Find, inclosing the "belt" and the "sword," a great trapezium of first-magnitude stars — Betelgeuse or alpha, Bellatrix or gamma, Rigel or beta, and Saiph or kappa.

Above the line joining Betelgeuse and Bellatrix find a little triangle of fourth-magnitude stars — phi 1 and 2, lambda. This marks the head of Orion.

Find a curve of fourth- and fifth-magnitude stars, convex toward Taurus — omicron 1 and 2; pi 2, 5, and 6. This curve marks the "lion's skin."

With the field glass look at the middle star of the "sword," theta Orionis, and find it nebulous. (A telescope shows this star to be quadruple and surrounded by the "great nebula in Orion.") Sweep with the glass near the triangle marking the head of Orion, and the region of the "belt," and find multitudes of stars.

Lepus. Below Orion find a little trapezium of third- and fourth-magnitude stars, marking the feet of Lepus — alpha, beta, gamma, delta. Connect another less regular trapezium — alpha, beta, epsilon, mu. Above mu find two pairs of fourth- and fifth-magnitude stars — lambda, nu; and kappa, iota — marking the ears of the hare. At the left of these pairs of stars a curve marks the body — zeta, eta, theta.

Canis Major. Southeast of Orion find the brightest star in the sky, Sirius, or alpha Canis Majoris. A sharp triangle marks the head of the dog — Sirius or alpha, gamma, theta. Southeast of this triangle find a triangle of second-magnitude stars—eta, epsilon, omicron, with a star in the middle, delta. These stars mark the haunches of the dog.

With the field glass examine nu and find it triple; also the cluster Messier 41, at the left of nu; also a small star near it, for contrast of color; also the region of delta, omicron 1 and 2, for streams of minute stars.

Canis Minor. Find a large triangle of first-magnitude stars — Betelgeuse or alpha Orionis, Sirius or alpha Canis Majoris, and Procyon or alpha Canis Minoris. Near Procyon find beta, surrounded by three fifth-magnitude stars. This marks the head of Canis Minor. One of these stars is ruddy.

Monoceros. This constellation, between Canis Major and Canis Minor, is a region in the Milky Way full of faint stars and clusters.

With the field glass examine this constellation for many rich fields.

CONSTELLATION STUDY FOR MARCH

Constellations of the Zodiac seen in Spring and Summer

Note. This study begins about right ascension eight hours.

Cancer. East of Gemini and a little south find a cloudy patch of nebulous light. This is Præsepe, the cluster in Cancer. Inclosing this cluster find a trapezium of fourth- and fifth-magnitude stars — delta, theta, eta, gamma. Delta and gamma were called by the ancients "Aselli" (*Præsepe* the manger, and *Aselli* the little asses).

From delta form a triangle with two fourth-magnitude stars — alpha, beta, delta. This marks the "claws of Cancer." (Near alpha is a fine telescopic cluster.)

With the field glass examine Præsepe and count the stars in the field. (Galileo saw thirty-six.)

Leo. Catch figure, a sickle of bright stars — Regulus or alpha Leonis, eta, gamma, zeta, mu, epsilon. East of the sickle find a large right-angled triangle of second-magnitude stars — Denebola or beta, theta, delta.

With the field glass look at beta, epsilon, and zeta, and note that they are double.

Virgo. A triangle of fourth-magnitude stars marks the head of Virgo — beta, nu, omicron. Note two pairs of fifth-magnitude stars, one above nu, the other between beta and omicron. Parallel and east of the line joining beta, omicron, find a line — epsilon, delta, gamma. Also find an oblique-angled triangle — delta, gamma, eta. (Gamma at the apex of the oblique angle is a telescopic double star, and eta is very near the autumnal equinox, the place where the sun is found on September 21.)

Find a trapezium of fourth-magnitude stars — theta, gamma, delta, zeta. (Zeta is on the equator.)

Below theta find a white star, Spica or alpha Virginis. (Spica is very near the ecliptic.) A trapezium of fourth-magnitude stars marks the feet of Virgo — mu, kappa, iota, 109. (The following stars bound a region full of nebulæ: Denebola, beta, eta, gamma, delta, and epsilon Virginis.)

Libra. A triangle of second-, third-, and fourth-magnitude stars marks the scales — gamma, alpha, beta. (Alpha Libræ is on the ecliptic.)

Scorpio. Catch figure, an old-fashioned kite outlined by bright stars. Sigma, pi, delta, beta, form the head of the kite; and Antares or alpha (a red star), tau, epsilon, mu, zeta, lambda, nu, form the tail.

With the field glass observe that Antares, sigma, and three faint stars make a pentagon in the glass. Just above this find rho Ophiuchi and 22 Scorpii, and see that each is double. Look at beta and see the pair below. Between Antares and beta find groups of stars. Above and at the left find gamma and note that it is double, the two components 40′ apart. Midway between beta and sigma find a star cluster.

Constellations North and South of the Zodiac in Spring and Summer

Leo Minor. Above the sickle in Leo find a triangle of third-magnitude stars and a group of fifth- and sixth-magnitude stars, forming Leo Minor.

Coma Berenices. Find the four first-magnitude stars which form what is called the "diamond in Virgo" — Denebola, Spica, Arcturus, Cor Caroli. Between Denebola and Cor Caroli is an open cluster marking "Berenice's hair."

Find that the field glass reveals rich fields of stars.

Hydra, Crater, Corvus. Below the cluster Præsepe find a group of six stars marking the head of Hydra — theta, eta, sigma, delta, epsilon, zeta. Trace a line of stars along the horizon which forms the coils of Hydra. Above these find a curve of fourth- and fifth-magnitude stars convex downward, marking the constellation Crater. A trapezium of third-magnitude stars east of Crater marks Corvus — beta, epsilon, gamma, delta.

With the field glass sweep the region of Crater and find many faint stars.

Boötes. Arcturus or alpha, a first-magnitude yellow star, forms with zeta and eta a triangle which marks the feet of Boötes. Above and west of the Northern Crown find a trapezium which marks the head and shoulders — delta, gamma, beta, mu. Between the head and feet find a triangle and two pairs of stars.

Corona Borealis. Southeast of Boötes find a semicircle of third- and fourth-magnitude stars convex downward — epsilon, delta, gamma, alpha, beta, theta.

Hercules. Catch figure, a butterfly flying toward Corona. Two trapeziums form the wings — epsilon, zeta, eta, pi; and epsilon, zeta, beta, delta. Find a triangle — beta, delta, Ras-Algethi or alpha Herculis. This yellow star, a telescopic double, marks the head of Hercules. From eta trace west, and up, a row of stars — eta, sigma, phi, chi, which marks one leg of Hercules.

From delta a line of fourth-magnitude stars — lambda, mu, xi, omicron — marks the "lion's skin," and a group of stars southeast the "sheaf of wheat."

Ophiuchus and Serpens. Near Ras-Algethi is a bright star, Ras-Alhague, or alpha Ophiuchi, which marks the head of Ophiuchus. Below this star find right and left pairs of stars marking the shoulders — beta, gamma; and iota, kappa.

Below Corona find a triangle of fifth-magnitude stars, the head of Serpens — gamma, beta, kappa. A line of stars curving downward, including several pairs of stars, marks the Serpent — delta with a fifth-magnitude neighbor, alpha, lambda, epsilon, mu; then delta, epsilon; farther east a triangle, nu, omicron, xi; then northeast, zeta, eta.

A group of fifth-magnitude stars above Antares marks one foot of Ophiuchus, and a group of second- and fourth-magnitude stars — theta, 16, xi, marks the other foot.

Great Circles of Reference

The equator. Beginning at the vernal equinox, where the autumn studies left it, the equator passes below the group of stars marking the head of Cetus, just above the belt of Orion, below Procyon, below the group marking the head of Hydra, below the triangle marking the head of Virgo. (The autumnal equinox is near eta Virginis.) The equator then passes north of gamma Virginis and through zeta Virginis, south of the pair of stars in Serpens (alpha, epsilon), below the triangle which ends the western branch of the Milky Way.

The ecliptic. Beginning at the vernal equinox, the ecliptic passes above the group which marks the head of Cetus, between the Hyades and Pleiades, just above mu Geminorum and eta Geminorum (the summer solstice is near these stars), just below Præsepe, just below Regulus, near eta Virginis. (The autumnal equinox is near this star.) The ecliptic passes next just above Spica, through the head of the "kite" which marks Scorpio, just above the "dipper" which marks Sagittarius. (The summer solstice is west of lambda Sagittarii.)

Note. The positions of the planets at any time can be found from the Ephemeris. Jupiter is about one year in a constellation, Saturn more than two years, Mars less than two months, Uranus about seven years, and Neptune about thirteen years.

It is interesting to note the differing configurations of the planets with the brighter stars. For example, in November, 1901, Saturn, Jupiter, Mars, Venus, and the new moon were together in the western sky in the constellation Sagittarius. This had not happened before since 1881. In November, 1907, Jupiter was in the center of a circle of eleven first-magnitude stars in Gemini, Auriga, Taurus, Orion, Canis Major, and Canis Minor.

EXERCISE XXXIV

MINUTE CONSTELLATION STUDY

Object. It is not possible in one year to become familiar with all the lucid stars, but as a sample of the minute knowledge of the sky which is necessary before one could, like Anderson of Edinburgh, detect the presence of a new star, it is well to make a detailed study of some one constellation.

Directions. Select some of the more interesting constellations. Study on the star atlas the positions of all stars visible to the naked eye. Identify each of these in the sky, recording in your notebook those identified, with the date on which they were seen.

EXERCISE XXXV

USE OF THE PLANISPHERE AND CONSTELLATION FINDER

Object. The motion of the sun eastward among the stars causes the constellations which appear in the evening to change from month to month, in a way puzzling to the novice.

A planisphere is a device by which the stars visible above the horizon at any hour on any date can be shown — those rising, those setting, and those on the meridian. The constellation finder shows the position of any constellation in the sky at any time.

Directions for planisphere. All the stars at any time visible in some intermediate latitude, as 45 degrees, are projected on a fixed circle, on the circumference of which are the days of the year. A movable circle revolves on a pivot in the center of this circle, which will be a point forty-five degrees from the pole star. In this movable circle is an opening, which is the projection of the horizon. This circle is supposed to make a complete revolution on its pivot in twenty-four hours, picking up new stars on the eastern horizon and covering those west.

To set the planisphere, bring the hour desired on the movable circle to the date on the outer circle. The horizon opening will inclose the stars above the horizon.

NOTE. Serviss's large planisphere is provided with thumb tacks to represent sun and planets. These can be placed from the Ephemeris or a table accompanying the chart. The revolving circle then shows the time of the rising and setting of these objects.

Directions for constellation finder. The constellation finder consists of a circular disk, on which the principal constellations visible in intermediate latitudes are projected in their proper right ascension, with the declination given beside the name. The center of this circle is pierced by a shaft parallel to the axis of the earth at the place where the instrument is to be used. At the end of this shaft is an arrow moving on an axis of declination and also of right ascension, like an equatorial telescope.

The following directions are from the pamphlet accompanying the instrument:

Place the instrument on a table with its axis parallel to that of the earth. Push the slide marked "to-day is" till it marks the day of the month. Turn the smaller movable circle until the desired hour is opposite the day (on the principle of the planisphere).

To find the place in the sky of any desired constellation, turn the pointer with the long opening to the desired constellation. Notice the declination + or − beside it. Push the arrow up or down until the + or − number comes to the index on the rod. The arrow is then pointing to the desired constellation at the hour.

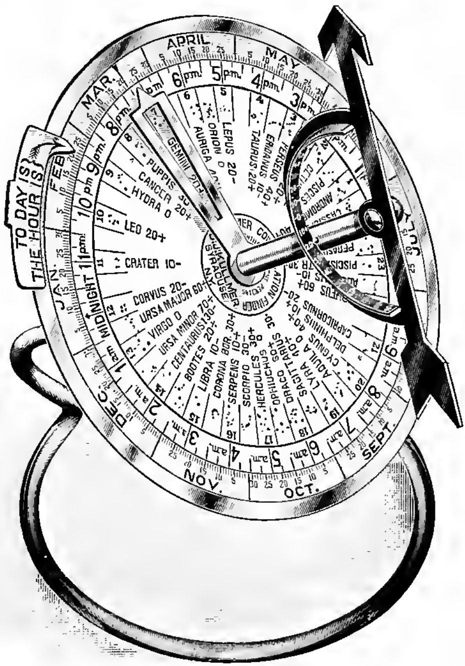

Fig. 17. Constellation Finder

To find when a constellation will be rising or setting, or on the meridian above or below, point the arrow at the desired point and then turn the dial until the constellation you wish to see comes to the indicator.

Suggestions for a variety of exercises may be found in the pamphlet.

EXERCISE XXXVI

TELESCOPIC OBSERVATIONS

Program of telescopic observations. Opportunity should be given in the course of the year for telescopic observations of the following objects at least: moon, Jupiter, Saturn, Mars, sun spots, Orion nebula, Castor, gamma Virginis, epsilon Lyræ, globular cluster in Hercules, Præsepe in Cancer.

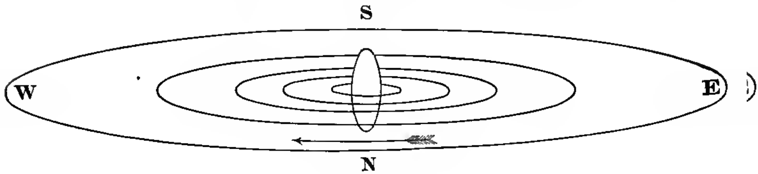

FIG. 18

Directions for record. In each case record the date and hour of observation, and the condition of seeing as "fine," "good," "fair," "poor."

THE MOON. Find from the Ephemeris, and record, the moon's age at the time of the observation. Draw in the notebook a circle, and from Colas's map put in the chief features identified, with their names. State what shadows, bright spots, or streaks are seen.

JUPITER. Consult the Ephemeris after the observation, and put in the notebook the little drawing of the planet and moons in proper position, with numbers on the side toward which the moon is moving. Copy the diagram (Fig. 18) for the orbits of the moons of Jupiter, and put dots for the moons in their approximate positions.

Write in your notebook answers to these questions:

1. How does Jupiter, which looks like a star to the naked eye, appear in the telescope?

2. Describe any markings seen on the disk, and name them by the diagram (Fig. 19).

3. State whether the equatorial and polar diameters of Jupiter seem equal, and which of the moons is largest and which smallest.

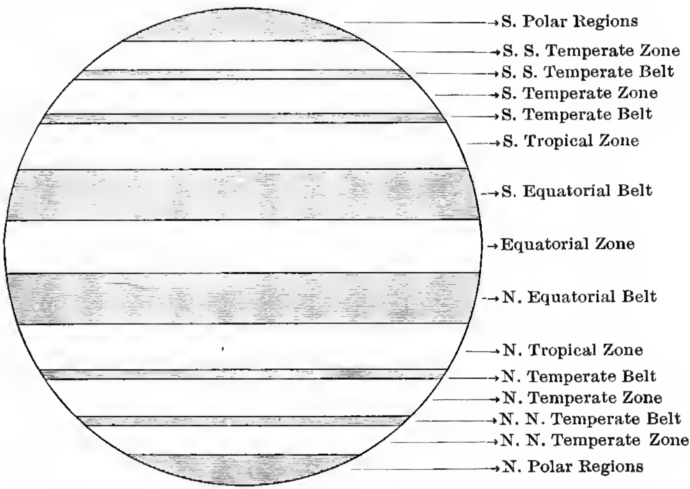

Fig. 19

Note. The diagram, Fig. 18, from the American Ephemeris shows the apparent motions of the moons from 1909 for a period of about five years, while the earth looks upon the south face of the orbits. After about half a revolution of Jupiter the orbits will present the other face to the earth, and the schematic drawing will change. For all detailed observations of Jupiter, or for the study of a succession of drawings, the scheme of nomenclature in Fig. 19 may be used.

Saturn. Draw the planet, rings, and moons as they appear in the telescope. Observe whether the rings extend beyond the disk a distance equal to the radius of the ball, more or less. Estimate the extent of the dark opening, and the positions in which the rings cross the ball, in terms of the diameter, and construct the drawing from these estimates.

Write in your notebook answers to the following questions:

1. How does Saturn, which looks like a star to the naked eye, appear through the telescope?

2. Describe the ring in words — whether in front of the planet above or below; whether wide open or narrow.

3. Can any break be observed between the ring and planet? If so, where, and how can it be accounted for?

4. Does the disk of the planet seem perfectly round?

NOTE. The rings of Saturn through half a revolution present their northern face to the earth, and during the other half, their southern. At the epoch 1912 we look upon the southern face, and they are widening out from year to year.

More advanced students should identify the moons of Saturn from night to night by the use of the Ephemeris and obtain the approximate time of the revolution of Titan.

MARS. Draw the planet as it appears through the telescope, and write answers to the following questions:

1. How does Mars, which appears like a star to the naked eye, appear through the telescope?

2. Describe color and any markings which are seen.

GREAT NEBULA IN ORION. As a preparation for observation, study Trouvelot's drawing or some other and copy it in your notebook. Write answers to the following questions:

1. Describe the appearance in the telescope of that which appears to the naked eye as the star theta Orionis.

2. How many stars in the heart of the bright nucleus?

3. What is the form and appearance of the brighter portion?

4. Describe the fainter streamers, especially the one extending upward on the "following side."

SUN SPOTS. Sketch the spots as they are projected on a screen and answer the following questions:

1. How many spots on the sun's surface?
2. Describe the different parts of each spot.
3. Are the spots isolated or in groups?
4. If in groups, how are larger and smaller spots disposed?

DOUBLE STARS. The record of observations with the telescope is more intelligent if data are given from authoritative sources; for example, gamma Virginis, α 12^h 35^m, $\delta - 0° 47'$. Components equal, A 3 magnitude, B 3 magnitude. Discussions of observations of this star taken since 1718 show it to be a binary system with a period a little less than two hundred years. The stars move in an elliptical orbit, and, as seen from the earth, the two components vary in distance from $0''$ to $6''$.

See's "Revolutions of Stellar Systems" and Burnham's "Catalogue of Double Stars" are useful references for double stars. The diagrams of stellar orbits from these authorities may well be copied in the notebook.

MULTIPLE STAR, EPSILON LYRÆ. The finder of the telescope shows this star widely double; the twelve-inch telescope shows each component to be a close double with six small stars between.

Webb's "Celestial Objects" gives the following data:

E_1, A 5 magnitude, B 6.5 magnitude.
E_2, A 5 magnitude, B 5.5 magnitude.
E_1 and E_2 distant $4'$.
Components of E_1 distant $3''.5$.
Components of E_2 distant $2''.5$.
Between A.D. 1779 and A.D. 1878 the right-hand component has moved clockwise.

EXERCISE XXXVII

PROGRAM OF OUTDOOR OBSERVATIONS FOR THE YEAR

Notebook records should be handed in monthly or at stated intervals, detailing naked-eye observations and field-glass work. These reports should include

1. The constellations identified from time to time by their catch figures, with dates of the observations.

2. The first-magnitude stars above the horizon, with names of those which have set and of those which have risen during the month.

3. The changing position of the circumpolar constellations.

4. The dates when the equator ecliptic and equinoctial colure are traced among the stars.

5. The motions, by alignment with the stars, of any planet which may be up.

6. The moon's motions, place of rising or setting, meridian altitude, position of crescent, conjunction with planets.

7. Sidereal time by Caph.

8. Measurements in degrees on the celestial sphere.

9. The magnitudes of stars by grades.

10. Observations of Algol.

Any other observations of phenomena in the sky.

NOTE. Record of star observations can often best be made by sketching the catch figures of the constellations along the ecliptic, the equator, the Milky Way, or about the pole. The record of the alignment of the moon or planets with the stars should be kept each on a page by itself.

EXERCISE XXXVIII

CHARACTERISTICS OF BRIGHT STARS

Object. After the year's study of elementary astronomy is nearly completed it is well for the instructor to review with appropriate comments our present state of knowledge in reference to the bright stars.

NOTE. The facts given below have been obtained from Harvard Revised Photometry (Harvard Annals, Vol. L); from the Draper Catalogue of Stellar Spectra (Harvard Annals, Vols. XXVI and XXVII); from Burnham's Double Stars; from the Catalogue of Spectroscopic Binaries (Lick Observatory Bulletins, Vol. VI); and from Catalogue of Variable Stars (Harvard Annals, Vol. LV).

Characteristics. *Sirius.* Magnitude, ~~1.4~~; color, white; distance, eight light-years; spectrum, type I A, a hydrogen star; a binary, accompanied by a massive but dim companion.

Capella. Magnitude, 0.2; color, yellow-white; distance, more than thirty light-years; spectrum, type II G, a calcium star exactly like our sun; swift radial velocity away from earth; a spectroscopic binary which no telescope has resolved, but one telescope has shown oval.

Rigel. Magnitude, 0.3; color, white; distance, beyond measure; spectrum, type I B; a companion blue, ninth magnitude, itself double. It is "almost certain that these stars, with a fourth, form a physical system."

Procyon. Magnitude, 0.5; color, yellow-white; distance, ten to twelve light-years; spectrum, type II F 5; a companion, predicted on account of Procyon's irregular motion in 1861, found in 1896. Its period is about forty years.

Arcturus. Magnitude, 0.02; color, yellow; distance, twenty-three light-years; spectrum, type II K — the spectrum of Arcturus is as if it were covered with sun spots;

very great tangential velocity, calculated to be two hundred fifty miles a second. When Arcturus appears in the eastern sky in the evening spring is near.

Vega. Magnitude, 0.2; color, bluish white; distance, thirty light-years; spectrum, type I A; velocity of approach, thirty-four miles per second; our sun and attendant planets are traveling toward Vega — near this star is the "apex of the sun's way."

Aldebaran. Magnitude, 1.0; color, rose-red; distance, thirty-two light-years; spectrum, type II K; swift velocity of recession.

Betelgeuse. Magnitude, 0.9; color, orange-red; distance, more than a hundred light-years; spectrum, type III Ma; receding; an irregular variable star of long period, its light varying a quarter of a magnitude.

Castor. Magnitude, 1.5; distance, more than sixteen light-years; spectrum, type I A; long known as a binary, each component lately shown to be spectroscopic binaries, so that Castor is a quadruple system of very long period.

Pollux. Magnitude, 1.2; color, yellow; distance, fifty-four light-years; spectrum, type II K; approaching.

Regulus. Magnitude, 1.0; color, white; distance, more than a hundred light-years; spectrum, type I A; receding.

Spica. Magnitude, 1.2; color, white; distance, beyond measure; spectrum, type I B2, a helium star; a spectroscopic binary. Spica is accompanied by a dark body.

Antares. Magnitude, 1.0; color, red; distance, more than a hundred light-years; spectrum, type III Ma; binary with a faint green companion of more advanced type.

Altair. Magnitude, 0.9; color, white; distance, fifteen light-years; spectrum, type I A; approaching. Most of the stars in the Milky Way belong to type I.

Deneb. Magnitude, 1.3; color, white; distance, beyond measure; spectrum, type I A; approaching.

Fomalhaut. Magnitude, 1.3; color, white; distance, twenty-one light-years; spectrum, type I A; one of the four royal stars of astrology — Regulus, Antares, and Aldebaran being the others.

Summary. If the light left Sirius or Procyon or Altair or Castor or Fomalhaut when a child was born it would reach the earth before he was of age. Betelgeuse, Antares, and Aldebaran are decidedly red; Arcturus, yellow; Capella, Procyon, and Pollux slightly golden; Rigel, Spica, and Deneb are distant beyond measure; Sirius, Rigel, Vega, Castor, Regulus, Spica, Altair, Deneb, Fomalhaut are type I stars with helium and hydrogen atmospheres; Capella, Procyon, Arcturus, Pollux are type II stars either approaching the state of our sun, exactly like it, or post-solar; Betelgeuse and Antares are type III stars with atmospheres highly condensed.

EXERCISE XXXIX

STUDY OF THE LOCUS OF SHADOWS

Object. The curves formed by the extremity of the moving shadow of a vertical post at various times of year, and in various latitudes, are most interesting æsthetically and mathematically, and afford further knowledge of the apparent motions of the sun.

Apparatus. The solar calculator (Fig. 20), consisting of a horizontal disk; a meridian circle; wire circles representing the paths of the sun at solstices and equinoxes; a sun-ray rod, used to locate the extremity of the shadow of the post, by placing it in the hour-mark notches.

Directions. Place a paper, cut to fit, on the horizon disk and mark on it the cardinal points. Loosen the vertical rod, or post, below, and slide it with the horizon plane, so that the sun-path circles are properly related to the meridian for the latitude. Make the horizon plane horizontal.

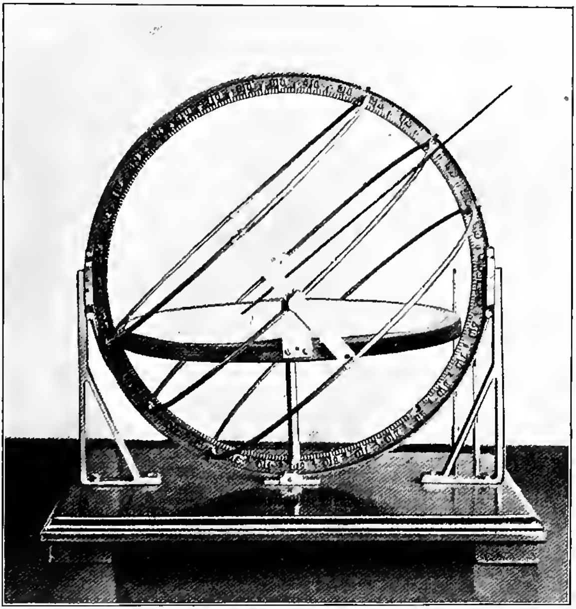

FIG. 20. THE SOLAR CALCULATOR

NOTE. The horizon disk, instead of being placed at the center of the sun-path circle, is lowered an amount equal to the height of the vertical post erected at the middle point. The Sun-Path Model (Fig. 21), referred to in Exercise V, shows more simply the circles as related to the horizon.

Loosely hold the sun-ray rod against the hour notch and the top of the post, beginning at sunrise, and dot on the paper the end of the shadow. In light pencil marks record the hour beside the dot. Do this for each hour till sunset.

Run a locus through the points and draw lines from the center of the paper, the foot of the post, to the hour points. These represent the shadows which extend from the post. Shadows near sunrise and sunset are too slanting to fall on the horizon. Fig. 22 shows the finished record for the arctic circle.

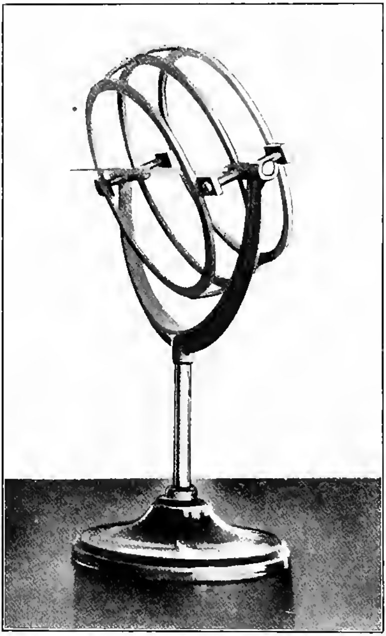

FIG. 21. SUN-PATH MODEL

Thus find the locus of the shadow for the solstices and equinoxes, at latitude 90°, the pole; at latitude 80°, a place within the arctic circle; at latitude 66°.5, on the arctic circle; at latitude 42°, or the latitude of the observer; at latitude 23°.5, the tropic of Cancer; and at latitude 0°, the equator.

Inspect the six charts after they are completed and labeled.

1. Notice that the locus of the shadow at the equinoxes in all latitudes is a straight line.

2. At the equator shadows at both equinoxes pass through the post. This indicates a vertical sun at noon.

3. The form of the locus at the solstices in all latitudes up to the arctic circle is an hyperbola; at the arctic circle it is a parabola.

4. Within the arctic circle, at the summer solstice, it is an ellipse or circle.

5. The sun's ray at the equinoxes is inclined to the vertical an amount equal to the latitude of the observer.

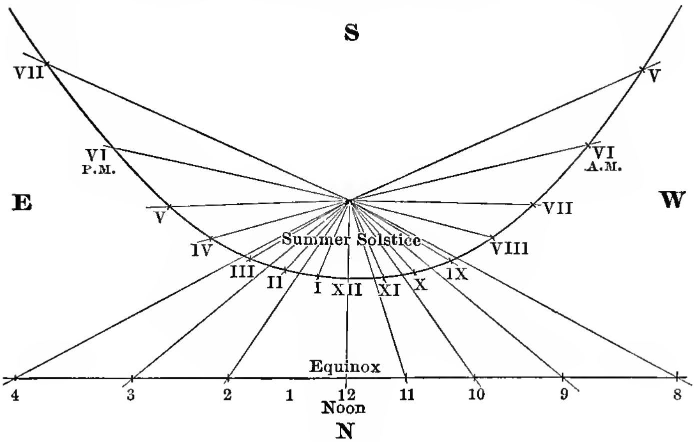

Fig. 22

6. In intermediate latitudes the shadows in winter are long, with long hour spaces; in summer they are short. The length of shadow changes rapidly in the early morning and in late afternoon.

7. At latitude 66°.5, the southern limit of the "midnight sun," at the summer solstice, the sun is due north on the horizon at midnight, and therefore the midnight shadow of a post would be of infinite length toward the south.

8. Latitude 80° is the lowest which will allow the curve at the summer solstice to fall entirely on the paper disk.

9. At the pole the shadow curve is a circle. When the sun is on the horizon, a circle of infinite diameter is formed. At the summer solstice the circle is of smallest diameter.

NOTE. Students with sufficient knowledge of mathematics should consult an article in *Popular Astronomy* (1908), p. 279, "The Path of the Shadow of a Plummet Bead," by Professor Ellen Hayes, which shows that the equations to the curves have coefficients which are functions of the declination of the sun and the observer's latitude.

EXERCISE XL

HELIOCENTRIC LATITUDE AND LONGITUDE OF SUN SPOTS

Material. For this work the Stonyhurst sun disks may be used, instead of the more laborious methods of computation. These disks, eight in number, are true orthographic projections of the parallels of latitude and meridians of longitude of the sun, corresponding to eight values of the heliographic latitude of the center of the sun's apparent disk. The use of the disks presupposes that the sun is observed by projection. For this a suitable frame must be attached to the eye end of the telescope, to carry a paper on which, by a proper eyepiece, an image of the sun six inches in diameter can be projected. There will be needed an "Ephemeris for Physical Observations of the Sun," which from 1913 will be given in the American Ephemeris. The "Companion" to the English journal, *The Observatory*, also gives this Ephemeris.

A table of natural cosines, a table to turn minutes into decimals of a degree, and a table for correcting the longitude for the time of observation will be needed.

Bauschinger's tables are good. Fig. 23 shows a good form of frame to carry the paper for the projection. A thin paper

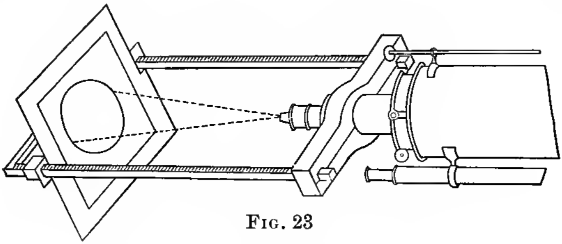

FIG. 23

should be used, so that, when it is placed over the disk, the parallels of latitude and longitude may show through.

1893, August 9.9^h 37^m

Ephemeris at time of Drawing:-

P	*D*	*L*
+14°.30	+6°.46	266°.56

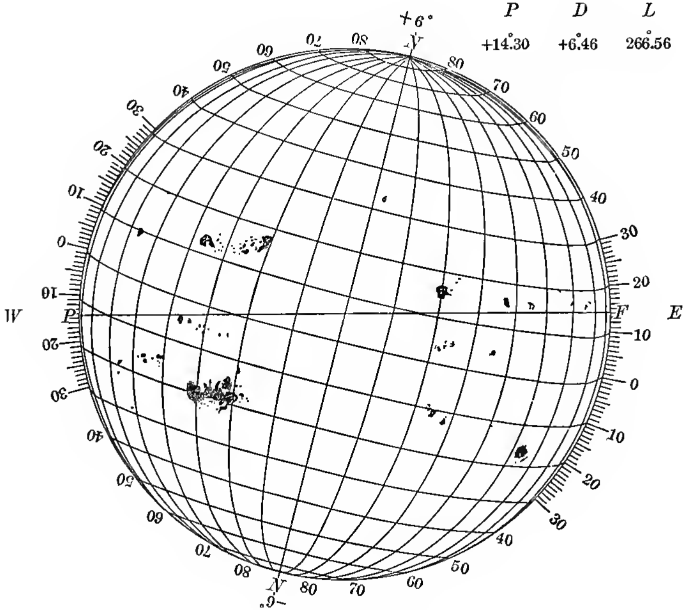

FIG. 24. SUN DISK

Directions. A series of observations of the solar disk should be taken with the telescope, the spots marked on the circles placed on the frame, and then an east-west line obtained by the trailing of a spot when the telescope is at rest. The date and hour of the observation should be recorded on the papers. For procedure in working up the heliocentric latitude and longitude of the spots, the student is referred to the pamphlet accompanying the sun disks. When a series of spots have been thus worked up and tabulated, the observations should be discussed. Fig. 24 shows the sun disk when placed under a paper on which spots have been traced.

EXERCISE XLI

TO MAKE A SUNDIAL

Object. The sundial, which keeps local apparent time by the movement of a shadow opposite the sun, has well been called "the astronomical instrument of sentiment and charm," since the sun describes his own progress on a dial plate. Many students would like to construct a dial for their home gardens. For the theory of dialing, consult the Encyclopædia Britannica; for an account of many of the dials of the Old World, with their mottoes, see "The Book of Sundials," by Mrs. Gatty, enlarged and reëdited (George Bell & Sons, London, 1900).

Directions. 1. For constructing a horizontal dial, a gnomon should be set up from the center of the dial plate, making an angle with the horizontal plane equal to the latitude of the place.

Next the dial plate should be set so that the gnomon is in the plane of the meridian. When it is local apparent noon, the shadow of the gnomon will be due south; this gives the twelve-hour mark.

For the construction of the angles which the shadow makes at different hours with the noon line, we have the formula

$$\tan x = \tan H \sin \phi,$$

where x is the dial angle from the noon mark right or left for the corresponding morning and afternoon hours; H is the hour angle of the sun 15 degrees, for 11 and 1 o'clock, 30 degrees, for 10 and 2 o'clock, and so on; ϕ is the latitude of the place.

Find the log sin ϕ once for all, and tabulate all the results as follows:

H	Log tan H	Log tan H sin ϕ	χ	Hour
15°				1 11
30°				2 10, etc.

Construct the angles from the twelve-hour mark with a protractor, the foot of the gnomon being the center of the angles.

2. In order to correct a watch keeping standard time by observation with the sundial, a dial with a larger and more finely graduated circle than is usual will be desirable; also a meridian-stone on which a meridian line has been laid down.

Place the dial on the stone, with its noon line in the meridian; let one student read the time while another reads the watch simultaneously. Correct the dial reading by the equation of time found in the Ephemeris, and correct this by the difference in time between the place and the standard meridian. The difference between this result and the reading of the watch is the error of the watch, fast or slow, of standard time.

EXERCISE XLII

STUDIES WITH HARVARD MAP PLATES

Object and material. The photographic chart plates called the "Harvard Map" were taken in 1899 and later, with an anastigmatic Cooke lens of aperture one inch and focal

Fig. 25. Viewing-Frame

length thirteen inches. More than 30 degrees square is covered by each plate. With exposures of one hour, stars as low as the twelfth magnitude are obtained. Fifty-five plates cover the sky. (See Harvard Circulars 69 and 71.) A viewing-frame (see Fig. 25) must be used. This frame just fits the plates, is inclined about 45° to the horizontal, and has placed beneath it a mirror — or better, white paper — to reflect light through the transparency.

The present study is designed to familiarize the student with the appearance of the photographed sky, and with methods of working with the plates. These plates are about four times the scale of the Durchmusterung.

Directions. Place the plates on the frame with the glass side up and film side down. Use an eyepiece for examination. For measurement use paper millimeter scales. Be sure to work in a good light.

1. *Plate 25.* Identify from a star chart the principal stars and record the x and y, that is the abscissa and ordinate of each. Record in tabular form.

Taking the right ascension and declination of Betelguese and delta Orionis from the catalogue for 1900, find the value of a millimeter in minutes of arc and of time, and calculate the right ascension and declination of the three stars in the belt, and of six of the brighter stars. In another column take these coördinates from the catalogue and find the residuals.

This method of finding right ascension and declination is rough, but could be carried to considerable refinement by finding the hour circles and parallels of declination by the method used with the fiducial stars in Roberts's Photographs. Identify the same stars on the Durchmusterung Charts, Numbers 3 and 4.

2. *Plate 12.* Identify and measure the x and y of the principal stars in the Pleiades, and of the brighter stars. Identify the same on the Durchmusterung Chart, Number 14.

Identify alpha Tauri, Aldebaran, and note that in this case, as in that of Betelgeuse, a red star shows a weak photographic magnitude.

Like studies can be made of any of the plates of the Harvard Map.

Study of the Harvard Map plates to identify clusters and nebulæ. Consult Harvard Annals (Vol. LX), and in the Introduction find Bailey's classification for clusters and nebulæ. Use Plates 12, 13, 18, 42, 43, or any others. Beginning with the upper left-hand corner, look across the plate with the eyepiece to detect nebulæ and clusters, and measure the x and y of objects found. Next go across the plate, lowering the eyepiece by its own width.

Head columns in your notebook as follows:

Number of Plate	N. G. C. Number	Other Name of Object	x y	Class	Remarks

Fill in this table with your own observations, and then compare with Professor Bailey's lists and put in the names of the objects.

EXERCISE XLIII

STUDY OF SPECTRUM PLATES

Material and object. Selected plates taken with the Draper telescope of Harvard Observatory, which uses a prism in front of the object glass, can be used to show the method by which the stars are classified by their spectra. Preliminary studies should be made of selected portions of Scheiner's "Spectrum Analysis," of the classification described in Harvard Annals (Vol. XXVIII, Part II), which is now in international use, and, if possible, of the "Annals of Tulse Hill Observatory" (Vol. I), by Sir William and Lady Huggins. In this volume can be studied a remarkable series of photographs of spectra of stars arranged in the probable order of their development, showing how the lines due to one element fade as those of another grow more intense.

The Harvard Classification, in brief, is as follows, with the corresponding types arranged according to the sequence at present accepted.

Type	Class	Spectrum
V	P	Only bright lines
	O	Continuous with bright lines
I	B	Helium lines prominent
	A	Hydrogen lines prominent
I to II	F	Hydrogen, some calcium and metallic lines
II	G	Solar lines, calcium prominent
II to III	K	Increased absorption
III	M	Titanium bands
IV	N	Carbon bands
VI	R	Bright and dark lines; too much violet for IV, too many dark lines for V

Directions. Placing the plate upon the viewing-frame, study it with the eyepiece; note the way in which the spectra are placed as to the violet and red ends. Identify the hydrogen and other lines; place the plate over the Durchmusterung Chart, which is taken to the same scale, and identify the stars. Finally, record in tabular form the class of each star and its x and y, using the same line of the spectrum for measurement in all cases.

Typical plates from the Harvard collection for this purpose are: Plate D, 8705, containing the variable chi Cygni; Plate D, 8719, in Cygnus, containing Wolf Rayet stars; Plate D, 8722, containing the Pleiades; Plate D, 15,449, containing the variable R Cygni, the plate of the cluster eta Carinæ.

EXERCISE XLIV

LIGHT CURVE OF VARIABLES IN CLUSTER OMEGA CENTAURI

Object. Variable stars have been found to be a special feature of globular clusters. In twenty-three clusters, five hundred twelve variable stars were found by Professor Bailey; in the cluster Omega Centauri alone there were one hundred twenty-eight (A.D. 1901).

This exercise shows the method of precedure in such variable-star work.

To find the light curve and period of all the variable stars in this cluster would require many more plates scattered at irregular intervals.

Material. Twenty-five selected plates of this globular cluster, a viewing-frame, an eyepiece. Book of reference, Harvard Annals (Vols. XXXVII–XXXVIII).

NOTE. These plates, taken at Arequipa at intervals between Julian day 2571 and 4480, with the thirteen-inch Boyden refractor, were kindly selected by Professor Bailey, so that they afford material for determining the light curve of a few stars.

Directions. 1. Choose a series of comparison stars near the marked stars 1, 2, and 8 on Plate I (Vol. XXXVIII). These stars, *d*, *e*, *f*, *g*, etc., range from the lowest to the highest magnitude attained by the variable stars.

The magnitudes of these comparison stars are taken from Table III, Sequences 1 and 2, in the volume referred to above. The frontispiece in this volume should be consulted, and the stars on the plates marked in ink on the glass side by letters identified on the map. The magnitudes of these comparison stars were determined photographically from the three zone-stars in the cluster. In the notebook, Table I should give these magnitudes in columns, thus:

DESIGNATION	MAGNITUDE
a'	9.02

2. Place the plates in order on the frame, and estimate the magnitude of each of the stars 1, 2, 8 by the method of grades. Observe the photographic image of the variable through the eyepiece, until a distinct impression of its brightness is obtained; then observe the comparison star, and so on, alternating, each observation lasting a few seconds. If the two stars appear equal after a careful examination, or if the star is brighter than the variable as often as the variable is brighter than the star, the magnitude of the variable is recorded as the same as that of the comparison star. If the variable appears more frequently brighter than fainter, the interval is designated as one grade. If the variable is certainly brighter than a comparison star, with, however, a very small difference, the difference is called two grades. A grade thus estimated slightly exceeds a tenth of a magnitude. (See E. C. Pickering's pamphlet on Variable Stars for this interpretation of the Durchmusterung method.) Repeat these observations a second time, selecting each time comparison stars which seem a little fainter and a little brighter than the variable.

Make Tables II, III, and IV, one for each of the three stars, with seven columns, thus:

PLATE NUMBER	JULIAN DAY	FIRST OBSERVATION	SECOND OBSERVATION	MEAN MAGNITUDE	EPOCH	PHASE

3. *Method of determining the periods of these variables.* Inspect the table and tabulate the Julian days at which the observations showed the star to be at a maximum, and the corresponding intervals; get the greatest common divisor of these intervals. Try the same method with the minima. If the number of observations is sufficient and the measurements are free from error, this should give the exact period of the star. This period should be tested by actual trial with all the measurements. The periods obtained may be compared with those given in the Harvard Annals. For definitive work the periods obtained from many more observations should be used.

4. *Method of obtaining the light curve.* For this we must choose an initial epoch and find the epoch and phase of each observation

The initial epoch chosen for each star is the time of maximum just before the observations began, obtained from the Harvard Annals.

For variable No. 1, period $29^d.34$, epoch J. D. 2566.08
For variable No. 2, period $484^d.00$, epoch J. D. 2205.99
For variable No. 8, period $0^d.521$, epoch J. D. 2571.37

For each observation the number of maxima since the initial epoch must be computed, and also the length of time since the next preceding maximum.

To do this, subtract the initial epoch from the Julian day of the observation and divide the remainder by the period. The whole number is the *epoch* of the observation, and the remainder is the length of time since the last preceding maximum, or the *phase.*

Place in the sixth and seventh columns the epoch and phase of each observation. The table now furnishes data for the light curves.

Plot on loci paper the light curves of these stars, using the *phases* as abscissas and the corresponding magnitudes as ordinates.

Run a smooth curve through these points.

5. Discuss each light curve, stating the times and methods of the waxing and waning of the light of the star.

EXERCISE XLV

STUDY OF NEBULÆ FROM PHOTOGRAPHS

Object. To find the positions among the stars of a few of the typical nebulæ, to study and draw their forms, and to demonstrate the remarkable advance made in our knowledge by the use of long-exposure photographs. In an illustrated lecture slides are shown in succession and but for a moment. It is desirable that the photographs should receive that prolonged and careful study which is required when they are drawn in the notebook.

Material. Lantern slides of a few of the typical nebulæ used as transparencies and placed side by side on a support constructed for the purpose. This support may be a wooden box with triangular sides, and a sloping face of ground glass inclined forty-five or more degrees and eighteen inches square. The interior of the box should be lined with asbestos, and two electric lamps placed within. A ledge should be made to support the slides arranged on the ground glass for inspection. Two such supports are desirable, in order that two sets of students may be drawing at the same time. Gaseous nebulæ may be arranged on one frame, spiral on another.

It is desirable to show the students the books from which many of the lantern slides were copied, namely, the Philosophical Transactions for 1844 and for 1850 (where Lord Rosse's drawings were published), Roberts's Celestial Photographs (Vols. I and II), the volume of the Lick Observatory publications containing the photographs taken with the Crossley reflector, the Astronomical Photographs of Yerkes Observatory, also the *Astrophysical Journal* (1910), in which some of Ritchie's photographs with the sixty-inch telescope of the Mt. Wilson Observatory were reproduced.

Directions. The instructor should first outline the work and require the student to look up on the star atlas the place of each nebula, so that when he looks at the sky he may think of it in its proper place. Next, notebook in hand, the student should study and draw the nebulæ, noting the development in our knowledge of their structure as methods of photography have been improved. Details as to the sources and characteristics of the photographs should be recorded somewhat as follows:

Class 1. *Gaseous nebulæ, mostly near the Milky Way.*

"The Crab Nebula," Messier 1 or N. G. C. 1952; α 5^h 28^m 30^s, $\delta + 21° 57'$, in Taurus.

Drawing by Lord Rosse shows an ovate body with filaments projecting.

Roberts's photograph shows the body of the nebula to consist of dense masses of clouds with sixteen stars involved.

Ritchie's photograph shows "countless antenna-like filaments surrounding the nebula.

The "Dumb-bell Nebula," Messier 27 or N. G. C. 6853; α 19^h 55^m 17^s, $\delta + 22° 26'$, in Vulpecula.

Drawing by Lord Rosse shows a form which gave the name to this nebula.

Roberts's photograph and later ones show great detail.

The "Ring Nebula," Messier 57 or N. G. C. 6720; α 18^h 49^m 32^s, $\delta + 32° 54'$, in Lyra.

Drawing by Lord Rosse shows merely a ring of nebulous matter.

Roberts's photograph shows an ellipse, brighter at the extremities of the minor axis.

The Crossley photograph, Plate 59, described by Keeler in "Astronomy and Astrophysics" (Vol. X), shows a thin veil of nebulosity over the opening in the ring, and a star of great actinic power near the center.

Ritchie's photograph with the sixty-inch telescope shows a "large amount of structure, three rings interwoven."

The "Owl Nebula," Messier 97 or N. G. C. 3587; α 11^h 9^m, $\delta + 55° 33'$, in Ursa Major.

Drawing by Lord Rosse shows two dark openings in an oval nebula which gave a resemblance to owl's eyes.

Roberts's photograph of four hours' exposure shows the nebula to be of elliptical form, with a fifteenth-magnitude star between the two dark spaces.

The Crossley photograph, Plate 27, shows much more detail.

Ritchie's photograph shows "an elliptical disk superposed on a fainter round one, much delicate shading, and the dark holes not round."

For a comparative study see *Monthly Notices* (Vol. LXVII).

The "Network Nebula," N. G. C. 6992; α 20^h 53^m, $\delta + 30° 49'$, in Cygnus.

Roberts's photograph (Vol. I), the Crossley photograph, Plate 63, and Ritchie's photograph, Plate 28, of the Astronomical Photographs of Yerkes Observatory show ever-increasing detail.

This strange nebula covers a vast region about three degrees southeast of epsilon Cygni. It is shown on negatives to be connected by delicate filaments with the nebula about the star 52 Cygni, which is southwest of it. Roberts calls attention to the fact that these nebulæ form a boundary between the crowded stars of the Milky Way and the more sparsely covered region beyond.

Class 2. Spiral nebulæ showing a continuous spectrum.

The "Andromeda Nebula," Messier 31 and 32; $\alpha\ 0^h 37^m 17^s$, $\delta + 40° 43'$, in Andromeda.

Nothing shows more strikingly the advance in knowledge of the universe made possible by photography than a comparison of Bond's wonderful drawing, shown in "Memoirs of the American Academy of Arts and Sciences," new series (Vol. III, p. 75), with the photograph taken by Ritchie with the two-foot reflector at Yerkes. The one is the result of detailed measurements on scores of nights. It shows a nucleus and two dark lanes, but no structure; the other, taken by an exposure of four hours, shows a right-handed spiral with central and outlying condensations — "a universe in the making."

The "Whirlpool Nebula," Messier 51, N. G. C. 5194; $\alpha\ 13^h 25^m 40^s$, $\delta + 47° 43'$, in Canes Venatici.

Drawing by Lord Rosse in 1850 showed an open right-handed spiral.

Roberts's photograph (Vol. I, Plate 30) shows stellar nuclei and the spiral broken with condensations.

Ritchie's photograph, Plate 29, of the Astronomical Photographs of Yerkes Observatory, and Keeler's photograph with the Crossley reflector, Plate 47, show further detail. Ritchie's photograph with the sixty-inch telescope shows "two hundred fifty nebulous stars, the space between the branches filled with faint nebulosity of exquisite lacelike structure."

Messier 63 or N. G. C. 5055; α 13^h 11^m 20^s, $\delta + 42° 33'.6$, in Canes Venatici.

Roberts's photograph (Vol. I) shows a left-handed spiral.

N. G. C. 4565; α 12^h 31^m 24^s, $\delta + 26° 32'.2$, Coma Berenices.

Roberts's photograph (Vol. I) shows a spiral seen edgewise, with central condensation.

Note. A piece of heavy copper wire bent into a spiral and viewed at various angles from both sides of its plane will illustrate many of the forms of nebulæ as seen from the earth.

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